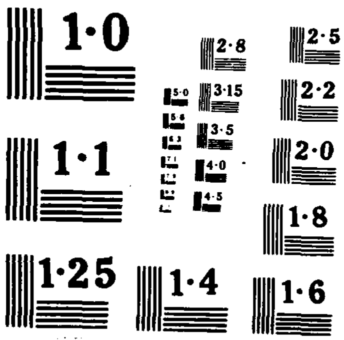
AD-A169 554   A COMPUTATIONAL STUDY OF THIN LAYER EFFECTS IN SHALLOW SEISMIC REFRACTION SURVEYS(U) AIR FORCE WEAPONS LAB KIRTLAND AFB NM R E REINKE MAY 86 AFWL-TR-85-81   1/1

UNCLASSIFIED   F/G 8/11   NL


1·0
2·8
2·5
3·15
2·2
3·5
1·1
2·0
4·0
4·5
1·8
1·25
1·4
1·6

AFWL-TR-85-81

AFWL-TR-
85-81

2

AD-A169 554

A COMPUTATIONAL STUDY OF THIN LAYER EFFECTS IN SHALLOW SEISMIC REFRACTION SURVEYS

R.E. Reinke

May 1986

Final Report

Approved for public release; distribution unlimited.

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117-6008

86 7 14 016

AFWL-TR-85-81

This final report was prepared by the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, under Job Order ILIR8307. Dr Robert E. Reinke (NTES) was the Laboratory Project Officer-in-Charge.

This technical report has been reviewed and is approved for publication.

Robert E Reinke

ROBERT E. REINKE
Project Officer

FOR THE COMMANDER

DAVID H. ARTMAN, JR
Major, USAF
Chief, Applications Branch

Carl L Davidson

CARL L. DAVIDSON
Colonel, USAF
Chief, Civil Engineering Research Div

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE:

3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): AFWL-TR-85-81

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: Air Force Weapons Laboratory

6b. OFFICE SYMBOL (If applicable): NTES

7a. NAME OF MONITORING ORGANIZATION:

6c. ADDRESS (City, State and ZIP Code): Kirtland Air Force Base, NM 87117-6008

7b. ADDRESS (City, State and ZIP Code):

8a. NAME OF FUNDING/SPONSORING ORGANIZATION:

8b. OFFICE SYMBOL (If applicable):

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS (City, State and ZIP Code):

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
61101F	ILIR	83	07

11. TITLE (Include Security Classification): A COMPUTATIONAL STUDY OF THIN LAYER EFFECTS IN SHALLOW SEISMIC REFRACTION SURVEYS

12. PERSONAL AUTHOR(S): Reinke, R.E.

13a. TYPE OF REPORT: Final

13b. TIME COVERED: FROM 1Feb83 TO 1Dec84

14. DATE OF REPORT (Yr., Mo., Day): 1986 May

15. PAGE COUNT: 48

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB. GR.
08	11	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number):

Seismic surveys; P-waves; Thin layers; Seismic refraction; Synthetic Seismograms; Wavelength; Geologic Models

19. ABSTRACT (Continue on reverse if necessary and identify by block number):

Seismic refraction surveys are a valuable tool for shallow engineering site characterization purposes. Standard refraction analysis uses first arrival time data to interpret subsurface layer velocities and thicknesses. In spite of their usefulness, refraction surveys suffer from several shortcomings. In this study, the practical influence of one of these shortcomings, the thin layer effect, was examined. Synthetic seismograms were computed, using the reflectivity method, for several thin layer models. These synthetic record sections were then treated as field data and the standard interpretation processes were performed. Significant discrepancies were observed in many cases between the true geologic model originally input to the code and the model interpreted from the synthetic record sections.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED X SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL: Dr Robert E. Reinke

22b. TELEPHONE NUMBER (Include Area Code): (505) 844-0484

22c. OFFICE SYMBOL: NTES

ACKNOWLEDGMENTS

Many useful discussions were had with Brian Stump of Southern Methodist University. He also assisted in implementation of the computer codes on the AFWL CRAY. Lane Johnson of the University of California at Berkeley is responsible for the version of the reflectivity code used to obtain the synthetic record sections. Rod Carroll of the United States Geological Survey reviewed the manuscript and suggested several improvements.

INTRODUCTION

Seismic refraction surveys are a valuable tool for shallow engineering site characterization purposes. Standard refraction analysis uses first arrival time data to interpret subsurface layer velocities and thicknesses. In spite of their usefulness, refraction surveys suffer from several well known shortcomings (for example blind zones and velocity inversions) and some not so well known difficulties, such as thin layer effects. In this study, synthetic seismograms were computed using the reflectivity method for several thin layer models. These synthetic record sections were then treated as field data and the standard interpretation processes were performed. The interpreted subsurface models were then compared with the true geologic model originally input to the reflectivity code to determine the practical problems associated with the conduction of refraction surveys in the presence of thin layers.

PREVIOUS WORK

Some studies of the thin layer problem for reflection surveys have been done in recent years (Refs. 1, 2 and 3). Studies of thin layer effects have been less prevalent, especially for shallow refraction surveys used in engineering site characterization. Several papers discuss the general physical phenomenon associated with thin layer propagation as important to seismic refraction surveys (Refs. 4-10). References 4 and 5 present the results of a laboratory seismic model study of refractions from layers of finite thickness. References 6 through 9 describe the results of calculational studies of thin layer headwave propagation, while Reference 10 discusses empirically derived attenuation coefficients for headwaves propagating in thin layers as opposed to those observed for propagation in thick refractors of two different types of lithology.

Before further discussion of thin layer refraction effects, a definition of what is meant by thin is required. The term thin is, of course, relative to the wavelength of the seismic waves propagating within a layer. Reference 10 defines thick as something greater than a few wavelengths; a thin refractor is said to be something less than about one-half of a

wavelength. As Reference 10 points out, however, these magnitudes are imprecise and will also depend on the impedance contrast between the layer and surrounding material and the observation range.

Refractions may become unreliable for velocity and depth determinations when they occur with wavelengths which are large compared to the layer thickness (Refs. 4-9). When layers become thin relative to wavelength, an interference condition is set up with multiply-reflected waves within the layer interfering with the headwave propagating within the layer. This results in increased attenuation as well as variations in phase velocity as a function of wavelength when compared to headwaves propagating in thick layers. This leads to various phenomena observed in refraction recordings, such as shingling discussed in Reference 6.

CALCULATIONS

The objective of this study was not so much a reexamination of the physics of thin layer wave propagation but a determination of its impact upon the results of shallow refraction surveys performed for engineering site characterization. Reference 11 presents a field example of a shallow refraction record section recorded in an area where a near-surface, thin high velocity layer overlies a fairly thin layer of lower velocity material, which in turn overlies a thick layer with approximately the same velocity as the near-surface layer. This subsurface configuration produced a refraction record section with a time gap. Consideration of geometric ray theory alone would predict that headwaves from the lower thick high velocity layer would never be observed as a first arrival. In reality, however, the wave propagating through the near-surface thin layer attenuated rapidly with distance, particularly for the lower frequencies. Eventually, the energy traveling through the near-surface thin layer dies out completely, leaving a fairly wide gap in time before headwaves from the lower thick layer arrive.

In the alluvial valleys of the Western United States, caliche deposits often form near-surface thin layers of relatively high velocity. Shallow refraction surveys are often performed in these areas to obtain material property information for use in the prediction and analysis of high-explosive test data. Often record sections are obtained which bear a strong resemblance

to those presented in Reference 11. A typical example recorded at White Sands Missile Range, New Mexico, is presented in Figure 1. If thin layer propagation effects are responsible for the time gap, as shown in Figure 1, then application of standard interpretation procedures will result in inaccurate models.

To determine the influence of these caliche beds upon the results of shallow refraction surveys, a series of synthetic refraction record sections were computed using the modified reflectivity method (Ref. 12). The reflectivity method allows the computation of complete seismograms, including surface waves, leaking modes, and all body wave phases. The method has been used to aid in the interpretation of very long range refraction data on the scale of tens to hundreds of kilometers (Refs. 13 and 14). To the best of our knowledge, the method has not been used before to aid in the interpretation of engineering scale refraction surveys.

The reflectivity technique was first developed by Fuchs as discussed in Reference 15. The technique uses the Thomson-Haskell matrix formalism and numerical integration in the frequency wavenumber domain to solve the equations of motion for a layered medium. Kind, as described in Reference 12, later extended the technique to compute synthetic seismograms for the case of a point source buried in a layered medium. The introduction of attenuation to the technique shifts the poles of the Rayleigh waves away from the real axis of the wavenumber plane allowing numerical integration along the real axis, thus, enabling the computation of complete synthetic seismograms rather than body waves alone.

The AFWL version of the reflectivity code first calculates the Green's function or impulse response for a layered medium. The Green's functions are then convolved with a source time function and instrument response function to produce a final synthetic seismogram.

Synthetic seismograms were generated for the two geologic models shown in Figure 2. These models are idealized approximations to the geology present at an alluvial high-explosive test site in New Mexico. The thin layer was intended to simulate a caliche bed possessing a moderate degree of cementation. The velocities shown in Figure 2 were derived from shallow refraction, uphole, downhole, and crosshole surveys. To determine the

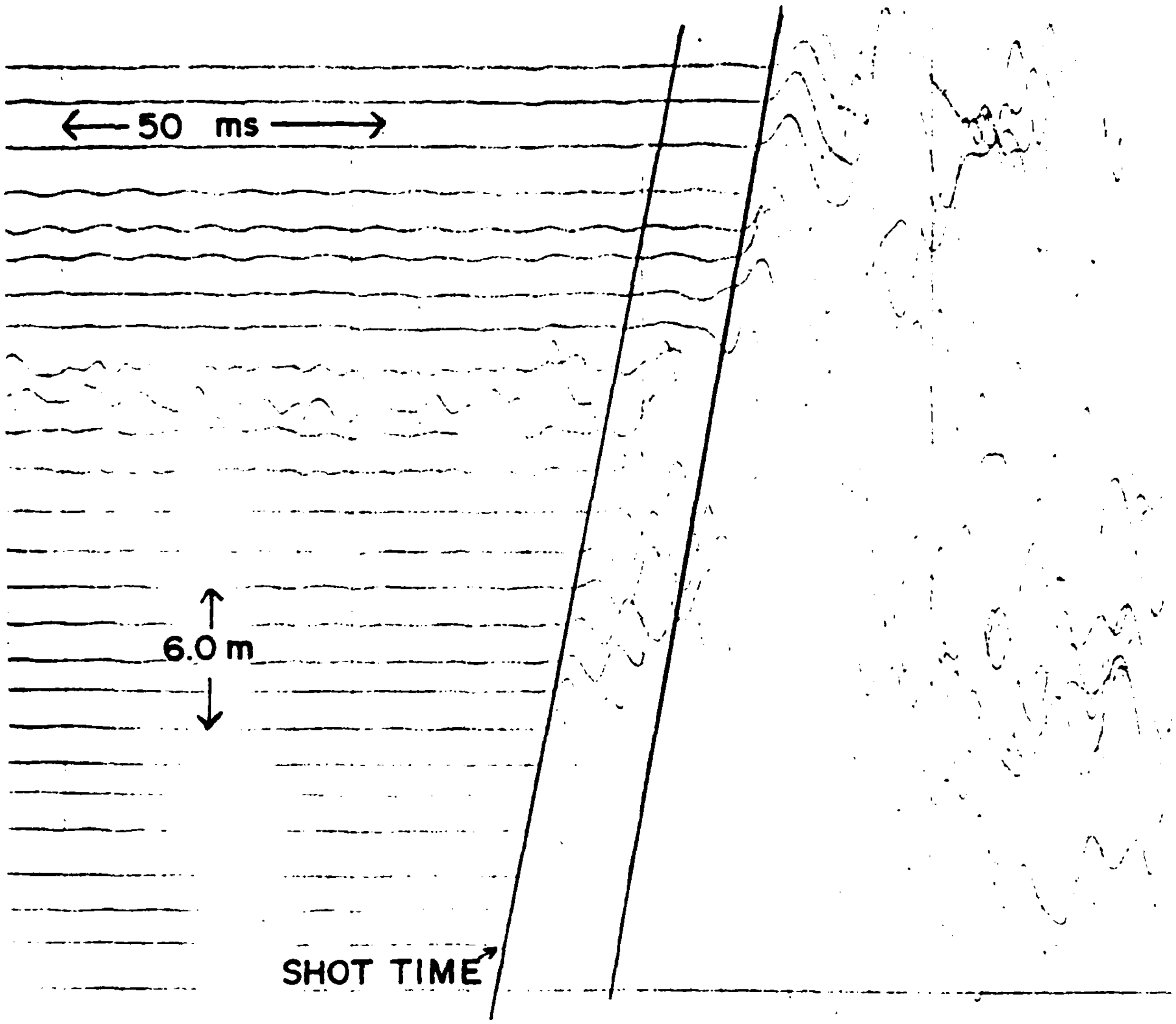


Figure 1. Example of field record section containing time gap (recorded in the northern Tularosa Basin on White Sands Missile Range, New Mexico).

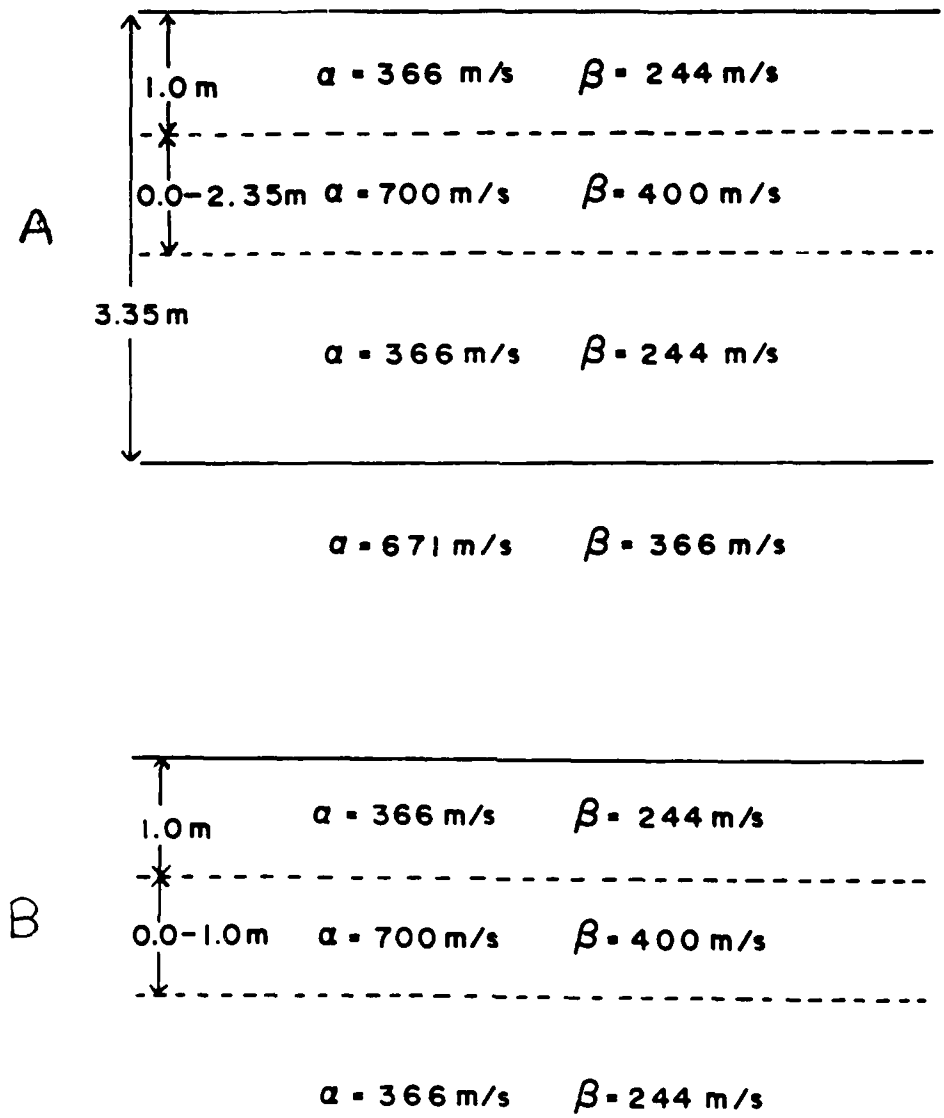


Figure 2. Computational models A and B for thin layer study.

effect of variations in thickness of the caliche layer upon the synthetic record sections, the thickness of the caliche layer was varied. The first set of calculations was performed for Model A, shown in Figure 2; the second set for Model B. Synthetic record sections were computed for Model B with thin layer thicknesses of 0.0, 0.06, 0.12, 0.25, 0.50, and 1 m. For the case where the subsurface half-space was included, Model A, synthetic record sections were computed for thin layer thicknesses of 0.0, 0.06, 0.12, 0.25, 0.50, 1, and 2.35 m. Synthetic seismograms were computed at ranges of 1.5, 3, 4.5, 6, 7.5, and 9 m.

A pure explosive source was arbitrarily placed at a depth of 1 m since the code does not allow the use of a surface source. After the bulk of the computations was completed, a few runs were repeated with a source depth of 0.5 m. No qualitative changes in the observed thin layer effects, due to the change in source depth, were obvious. The time function for the source consisted of a step function with a second order polynomial rise time of 5 ms. The instrument response was constructed to closely approximate the response of the typical shallow refraction seismic recording system. The geophone response simulated 4.5 Hz natural frequency units damped at 0.707 critical. The recording system response rolled off at 400 Hz. A total of 256 samples was computed for each synthetic seismogram. The sample interval was 0.3 ms. Some runs were made with a source rise time of 2 ms. The reflectivity code includes attenuation effects. For these runs, all P wave Q factors were set equal to 100, S wave Q factors were set equal to 44.

An estimation of the wavelength for the energy propagating in the thin bed may be made by assuming the period to be equal to the rise time (5 ms) of the source. This yields a P wavelength of 3.5 m for energy in the caliche layer and 1.8 m in the surrounding alluvium. For the high frequency source (2 ms), we have a caliche wavelength of 1.4 m and 0.73 m in the surrounding material.

RESULTS OF THE CALCULATIONS

Vertical and radial synthetic record sections are shown in Figures 3 through 14 for thin layer thicknesses of 0.0, 0.06, 0.12, 0.25, 0.50, and 1 m for the subsurface model (Model B) without the lower half-space. The

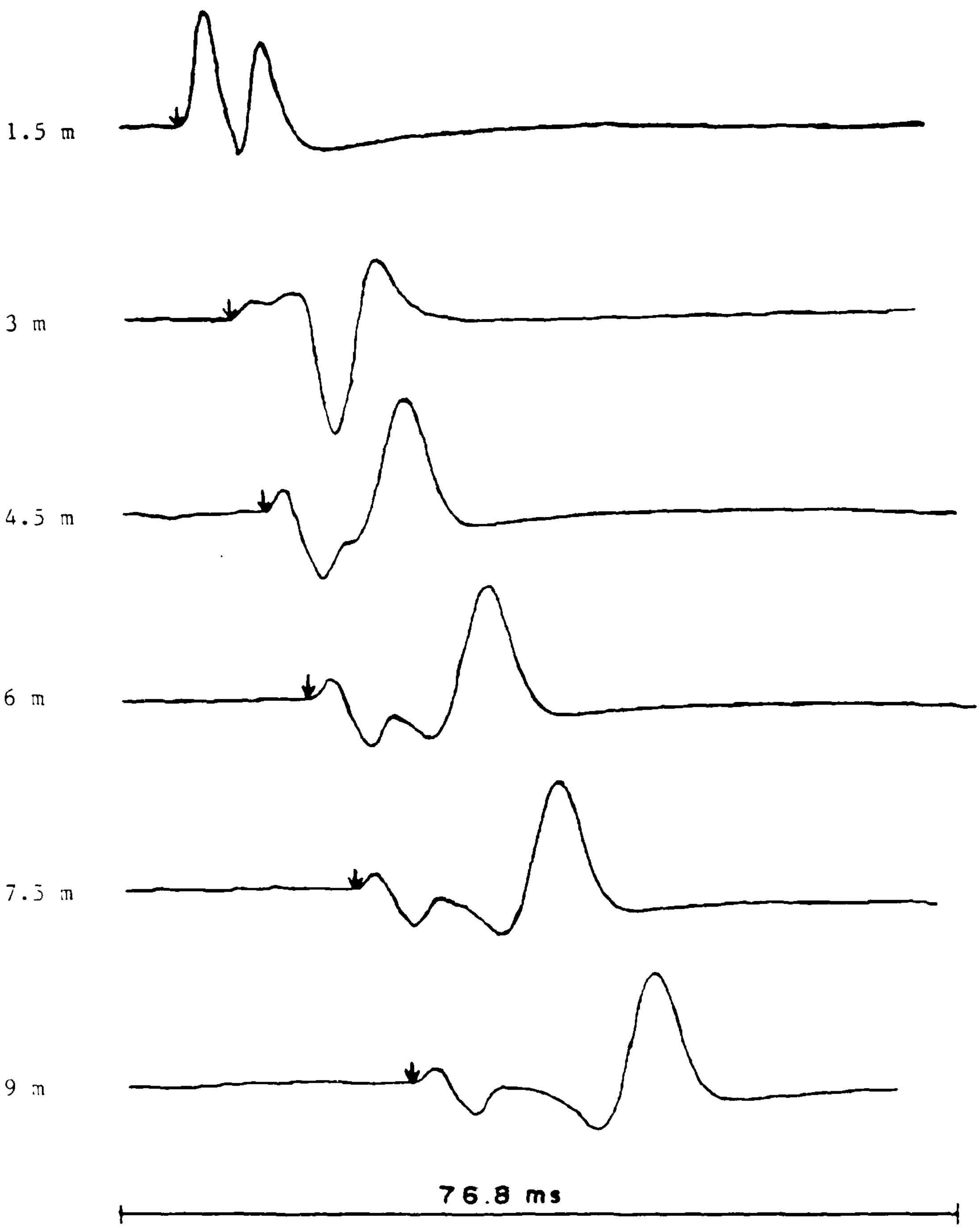


Figure 3. Vertical synthetic record section for model B with no thin layer.

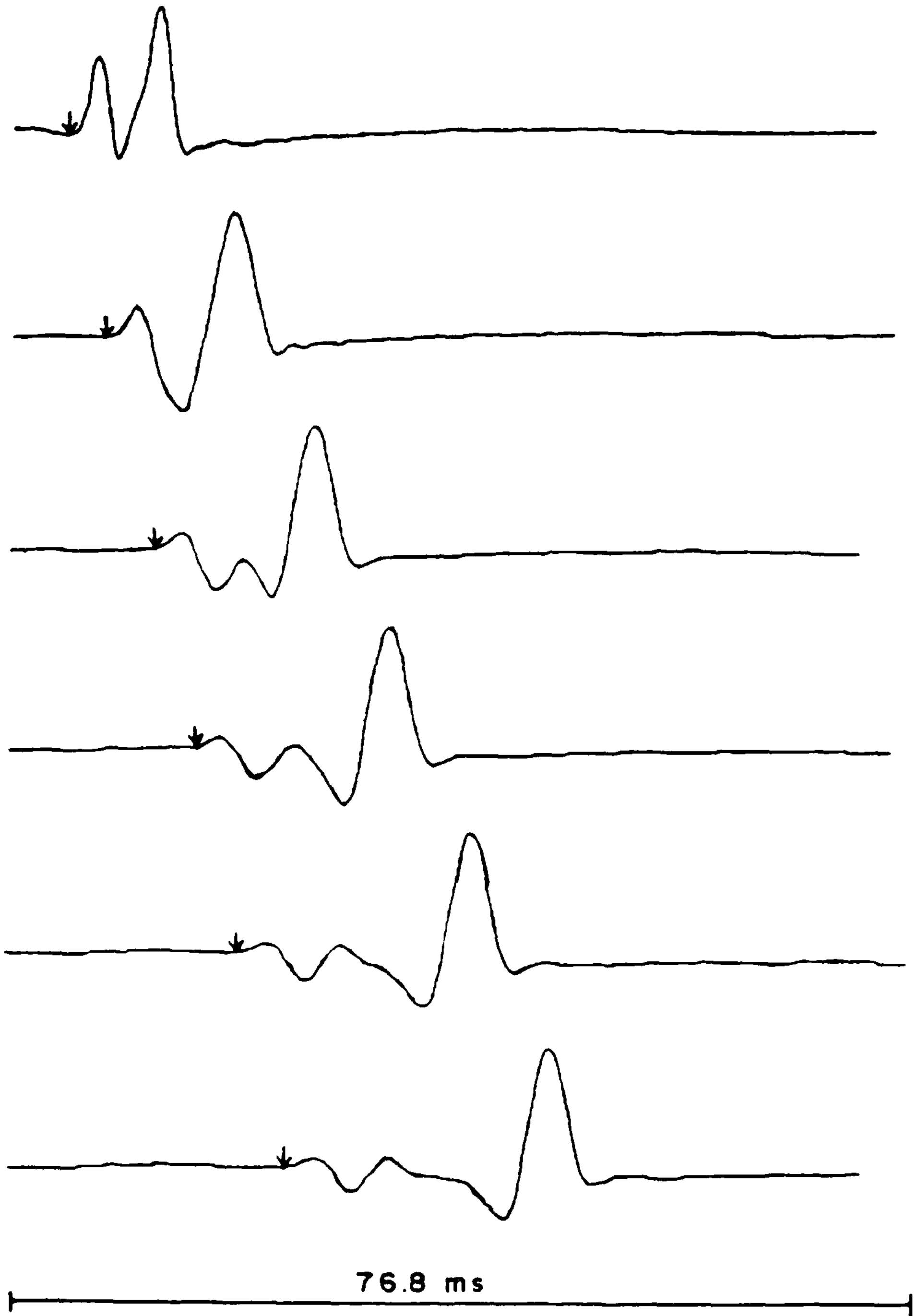


Figure 4. Vertical synthetic record section for model B with 0.06 m thin layer.

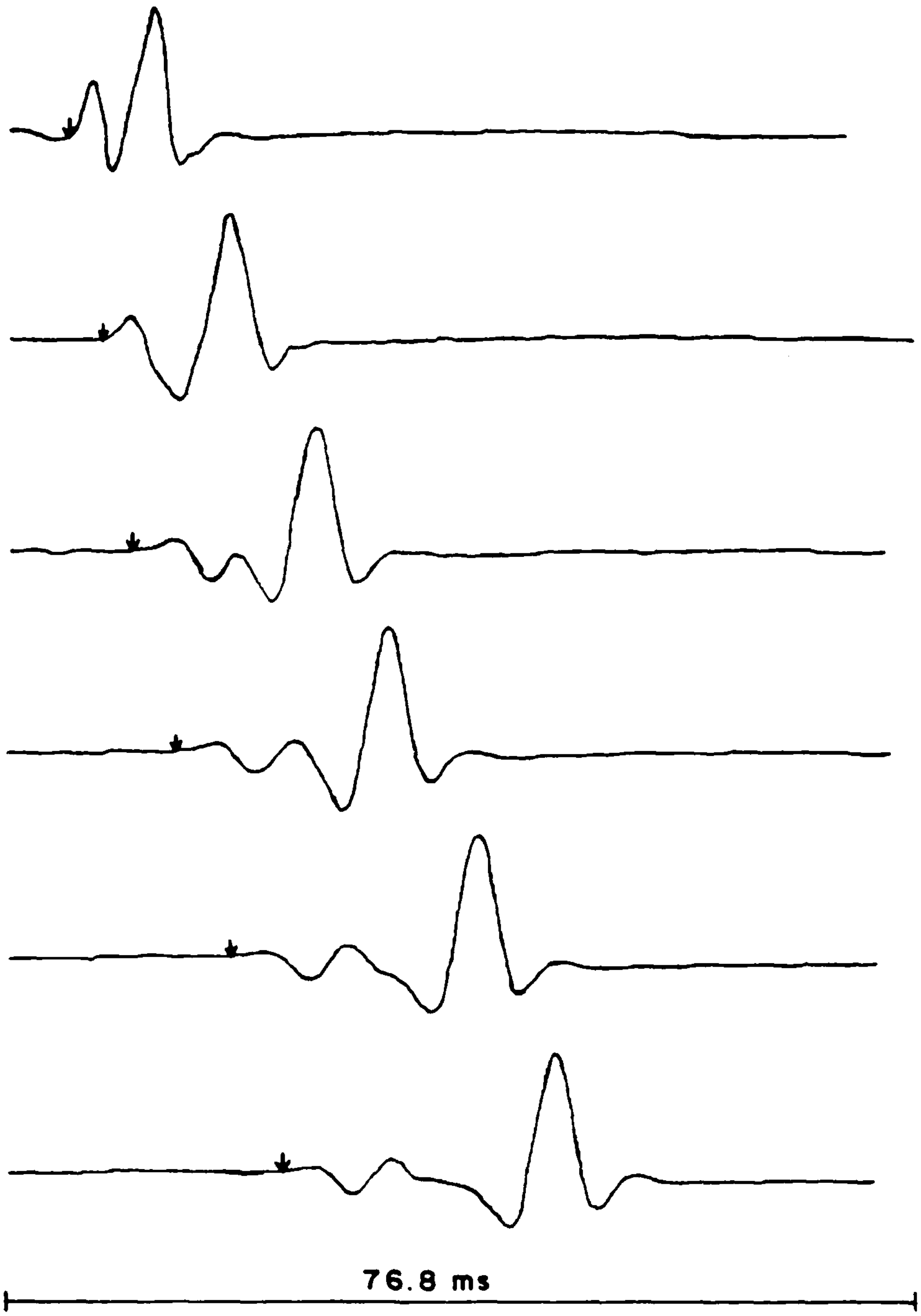


Figure 5. Vertical synthetic record section for model B with 0.12 m thin layer.

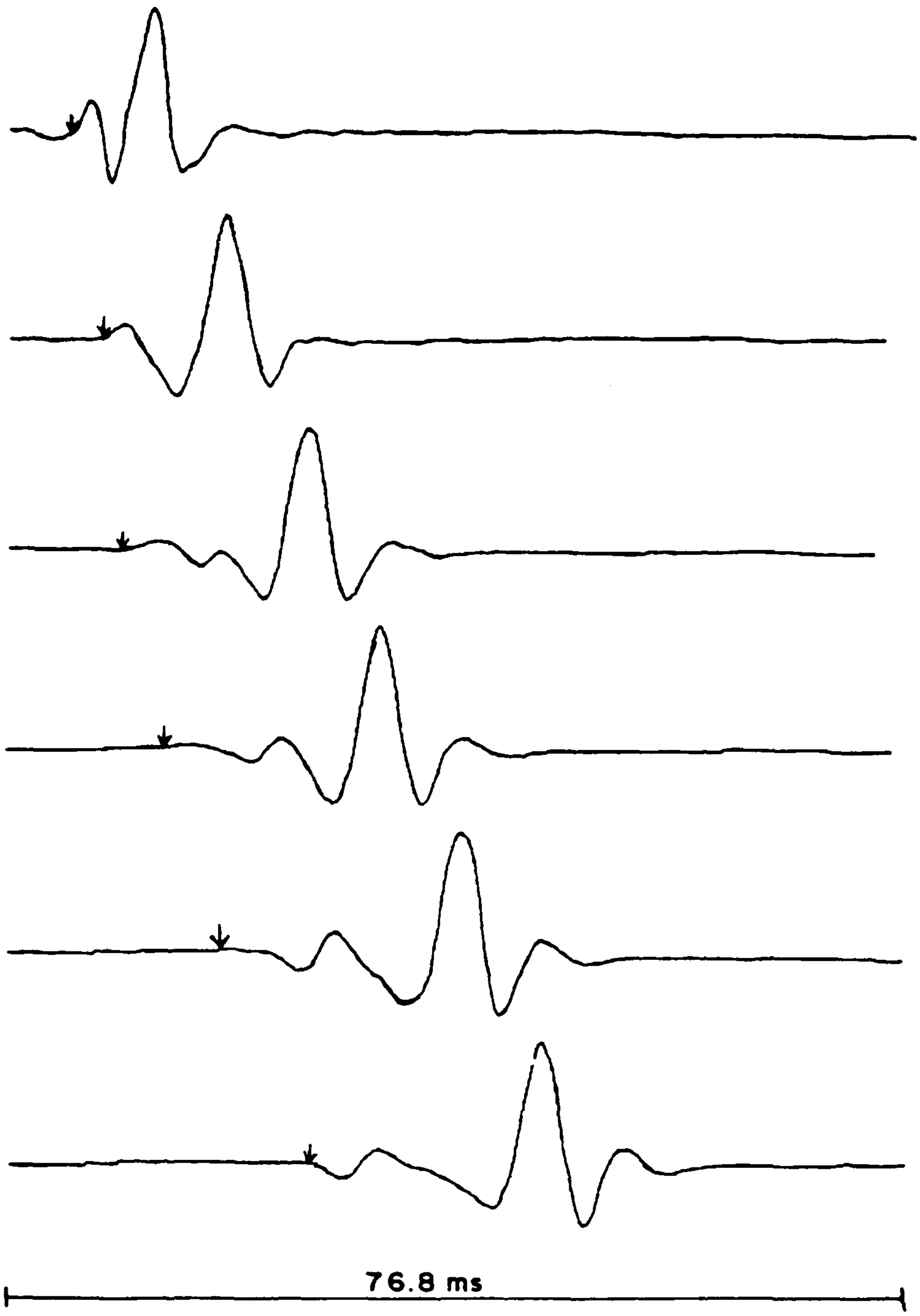


Figure 6. Vertical synthetic record section for model B with 0.25 m thin layer.

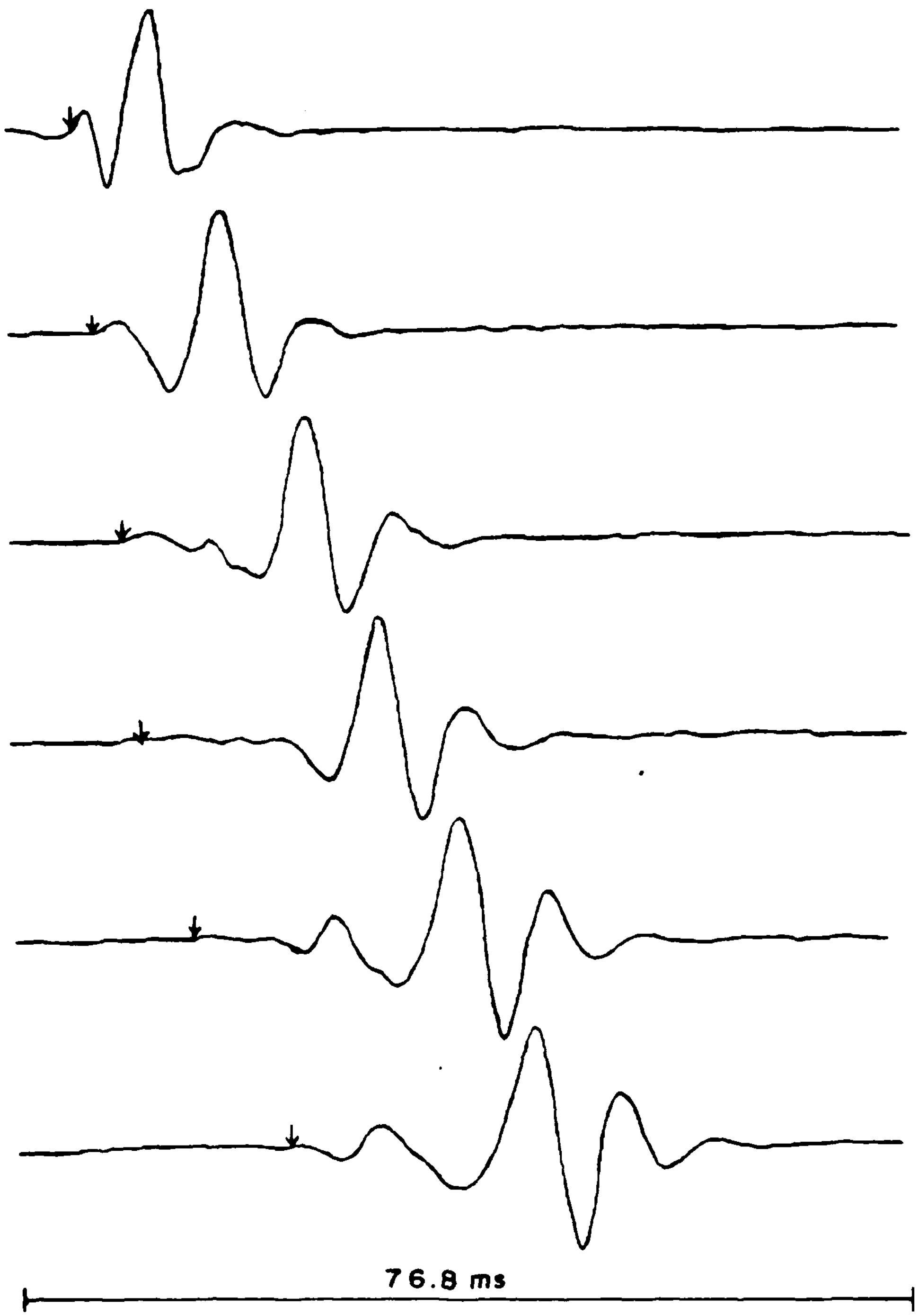


Figure 7. Vertical synthetic record section for model B with 0.50 m thin layer.

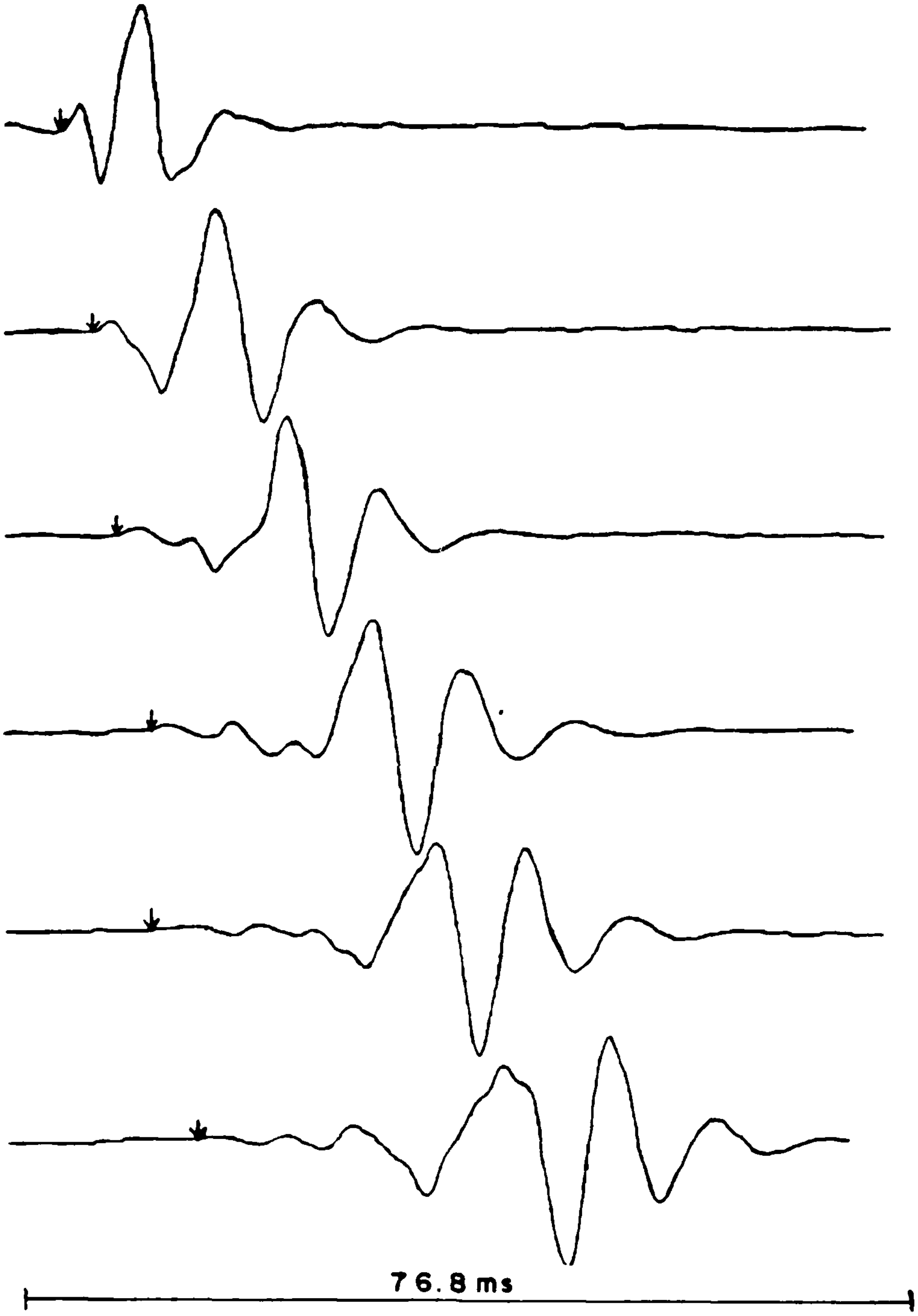


Figure 8. Vertical synthetic record section for model B with 1 m thin layer.

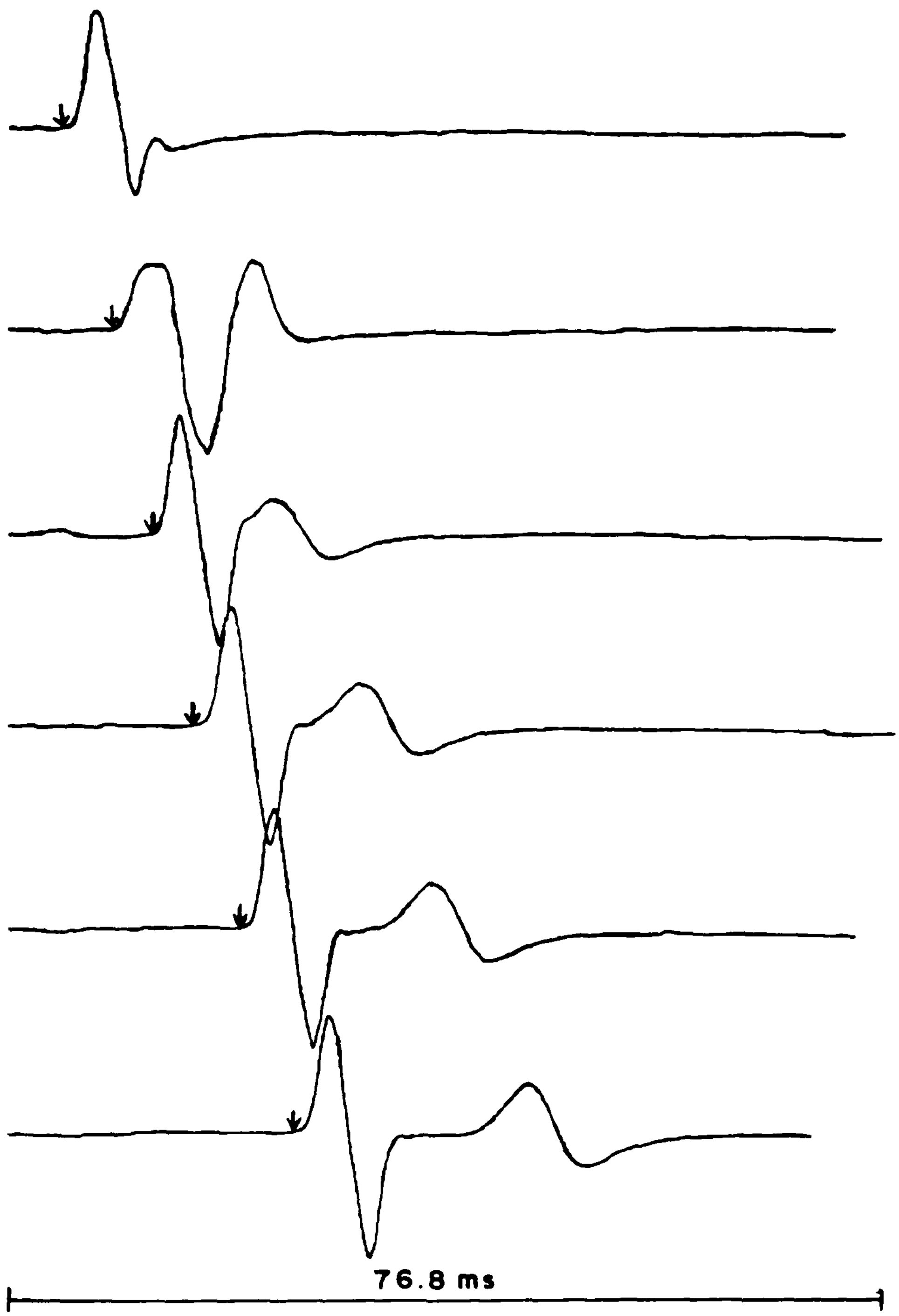


Figure 9. Radial synthetic record section for model B with no thin layer.

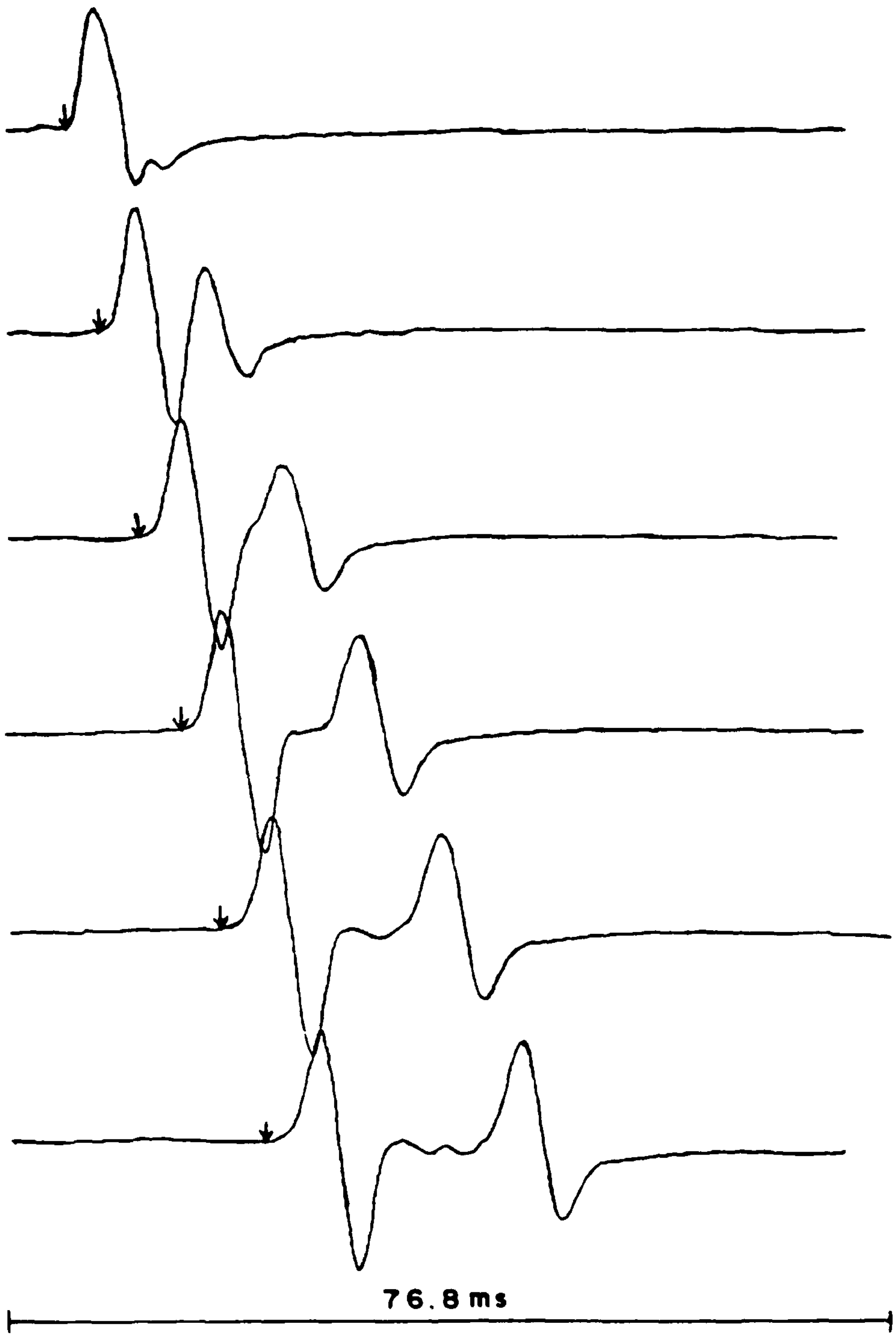


Figure 10. Radial synthetic record section for model B with 0.06 m thin layer.

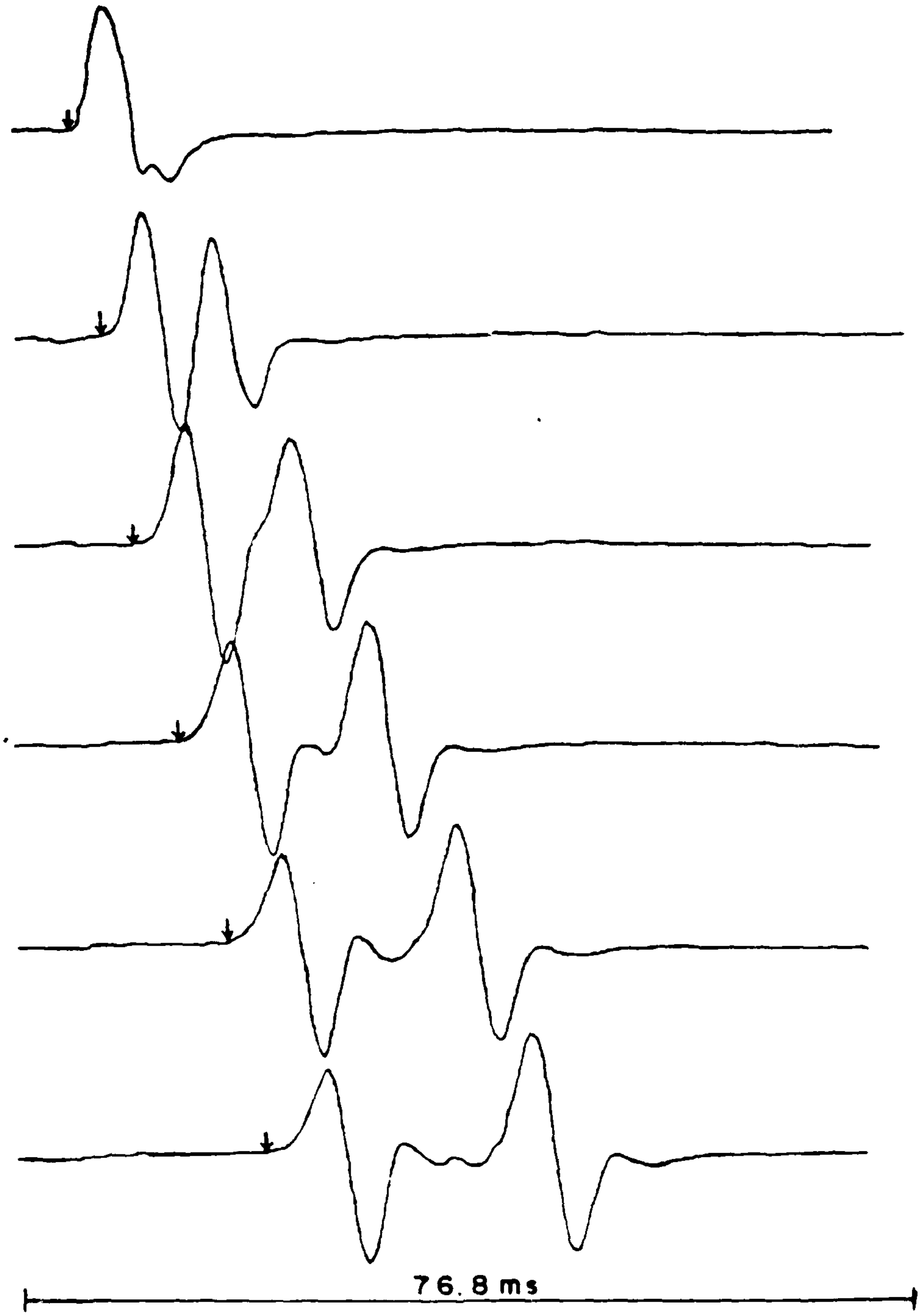


Figure 11. Radial synthetic record section for model B with 0.12 m thin layer.

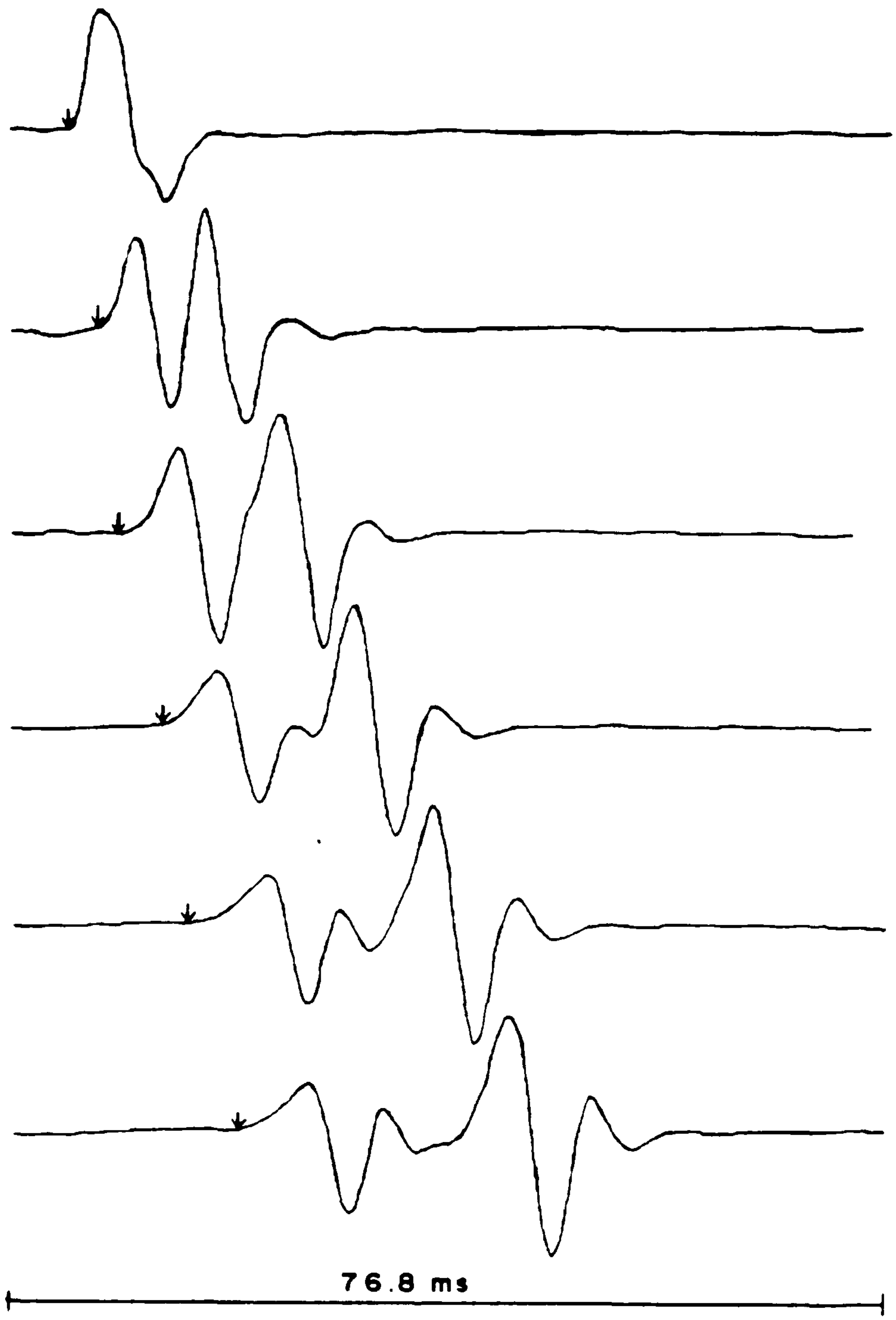


Figure 12. Radial synthetic record section for model B with 0.25 m thin layer.

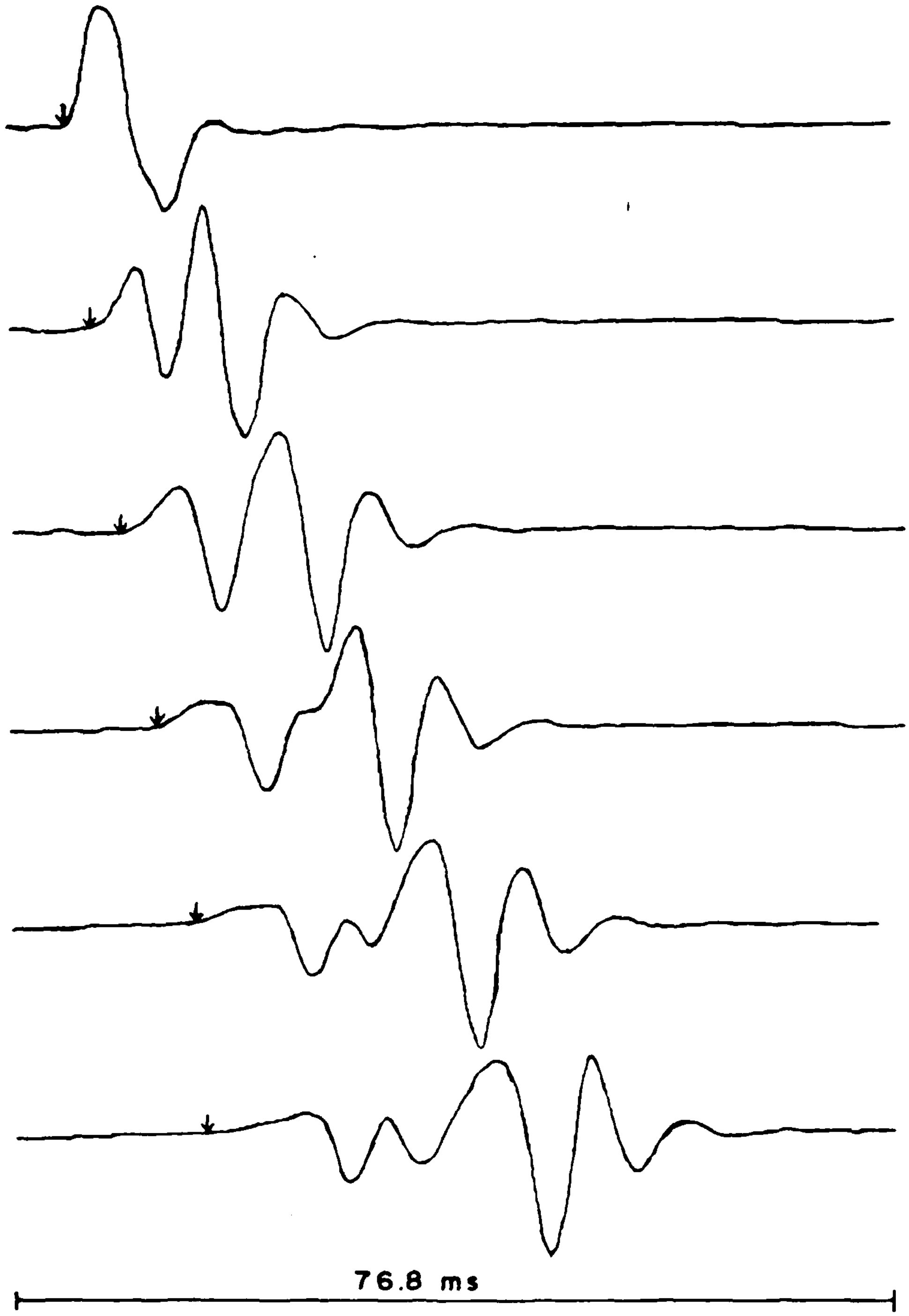


Figure 13. Radial synthetic record section for model B with 0.50 m thin layer.

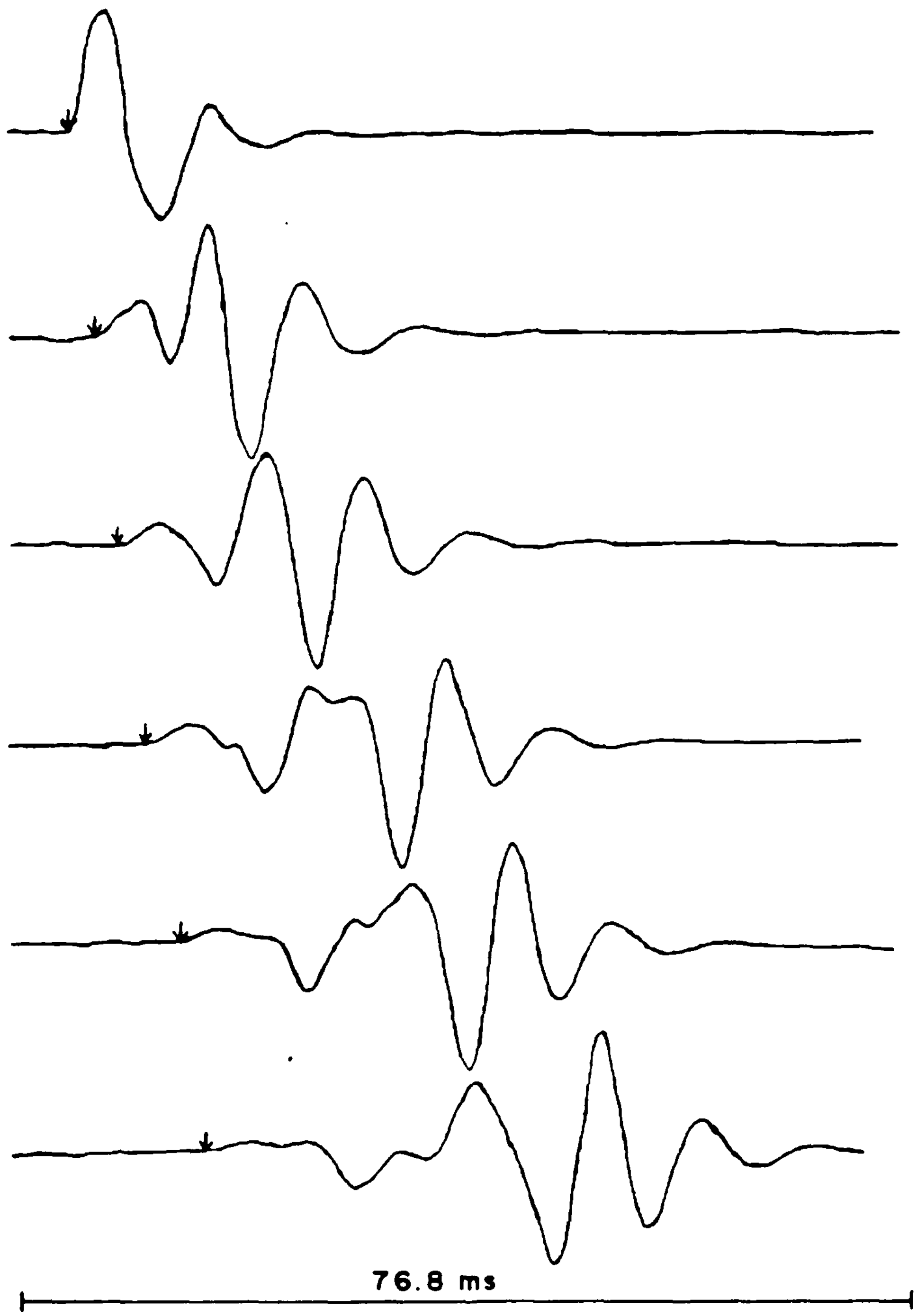


Figure 14. Radial synthetic record section for model B with 1 m thin layer.

arrows in these figures indicate picks of the first arrival time. The source rise time used for the calculations shown in these record sections was 5 ms.

Examination of the record sections in Figures 3 through 14 reveals the effects of changing thin layer thicknesses upon the appearance of the synthetic seismic sections. The most striking effect is the weakening of the first arrival in the waveforms, particularly on the vertical component. After the thin layer reaches 0.12 m thickness, the first break becomes emergent and difficult to pick.

Figures 15 and 16 illustrate the changes in the waveforms which occur at 6 m range with changes in the thickness of the caliche layer. A well-defined clear first arrival is apparent on the 0.0 m thickness thin layer waveforms. This arrival becomes less defined as the thin layer thickness increases. The first breaks appear to be stronger on the radial component.

Some synthetic record sections have a qualitative similarity to the field record section in Figure 1, although the purpose of the calculational effort was not to directly model the Figure 1 records. As in the synthetic record sections, a region appears in the field section (just past halfway through the spread) where the first arrival becomes very emergent and then dissipates completely. In the field section, a strong arrival resumes at a later time creating the characteristic time gap in the travel time curves. The synthetic sections do not extend far enough in range to show clearly the resumption of strong first arrivals after the region where the initial first arrival decays.

All subsurface models for which the calculations were performed are, of course, examples of velocity inversions. The thin layer is, in each case, higher in velocity than the underlying material. Purely geometrical ray theory would predict then that the material beneath the thin layer would never be detected by standard refraction interpretation techniques. The purpose of this study was not an attempt to develop a technique for solution of the velocity inversion problem, but to examine the departure from geometric ray theory under conditions when the thickness of a geologic bed is small when compared to the wavelength of the seismic energy used in a refraction survey.

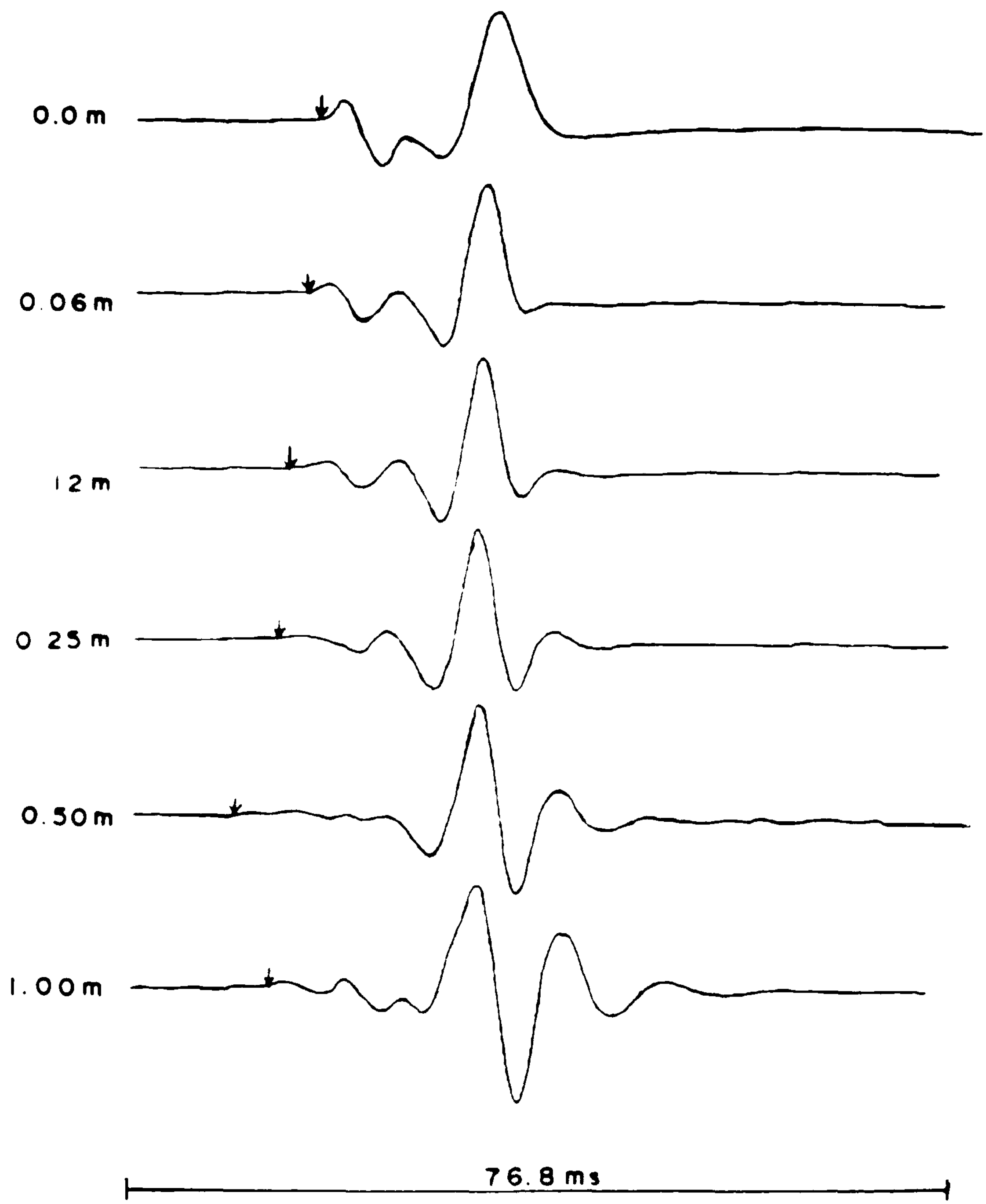


Figure 15. Comparison of vertical synthetic seismograms for the thin layer thickness indicated, model B, 6 m range.

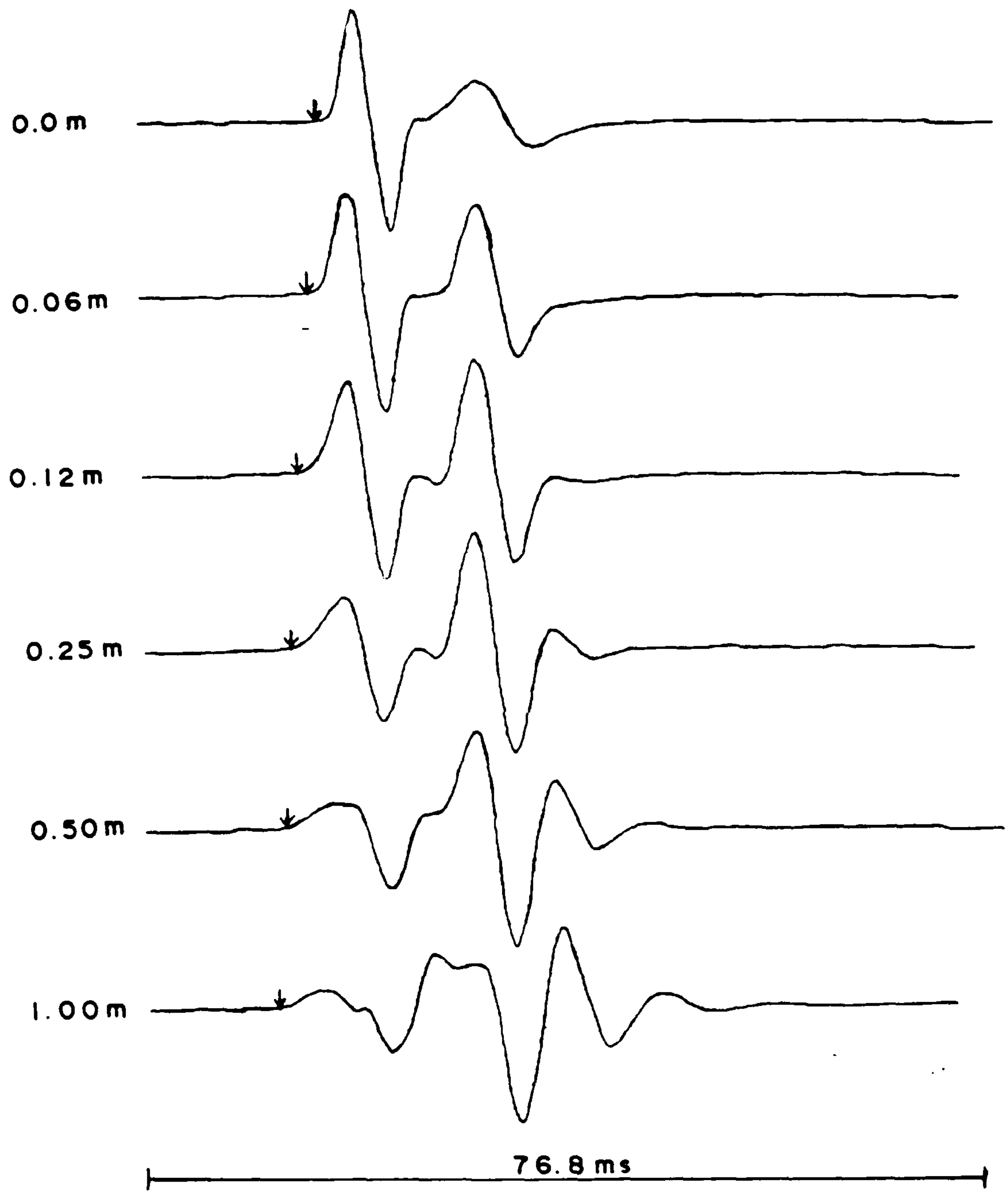


Figure 16. Comparison of radial synthetic seismograms for the thin layer thickness indicated, model B, 6 m range.

To gain some insight into thin layer effects upon the results of shallow refraction surveys, the synthetic record sections were treated as real field data and first break times picked as indicated by the arrows in Figures 3 through 16. Travel times from all the record sections are shown in Figures 17 through 23. The solid lines indicate true travel times computed for the models for waves propagating in the near surface material and the thin fast layer assuming geometric ray theory. The near source curvature of the 366 m/s curve, as well as the non-zero intercept of both curves, results from the 1 m depth of the source. The data points are the first break times determined from all the synthetic record sections.

Comparison of the theoretically predicted travel times in Figures 17 through 23, with the first break times picked from the synthetic record sections, reveals large discrepancies between the observed and predicted values for the thinner layers. There is a good correlation between the observed and geometrically predicted arrival times for the 2.35 m thickness case. The 2.35 m case can, however, hardly be considered a thin layer case since the caliche layer lies directly on top of the lower half-space which has velocities near those of the caliche layer.

How do the discrepancies between the first break picks and the true (geometrically predicted) travel times affect what the interpreted subsurface structure will be compared to the true (that which was input to the reflectivity code) structure? To determine the errors which would be present in the interpreted subsurface model had the synthetic record stations been real field data, some of the picked first break times were input to an automated seismic refraction interpretation code. This code, SIPT, is a 24-geophone version of the code described in References 16 and 17. The code accepts time distance data from refraction surveys and uses a delay time approximation to produce a first cut subsurface model. This model is then adjusted by up to three passes of ray tracing to reduce the discrepancy between observed and computed arrival times at each geophone. Output of the code is a velocity-depth structure containing up to five layers. The SIPT code is used as part of the standard refraction interpretation process at AFWL.

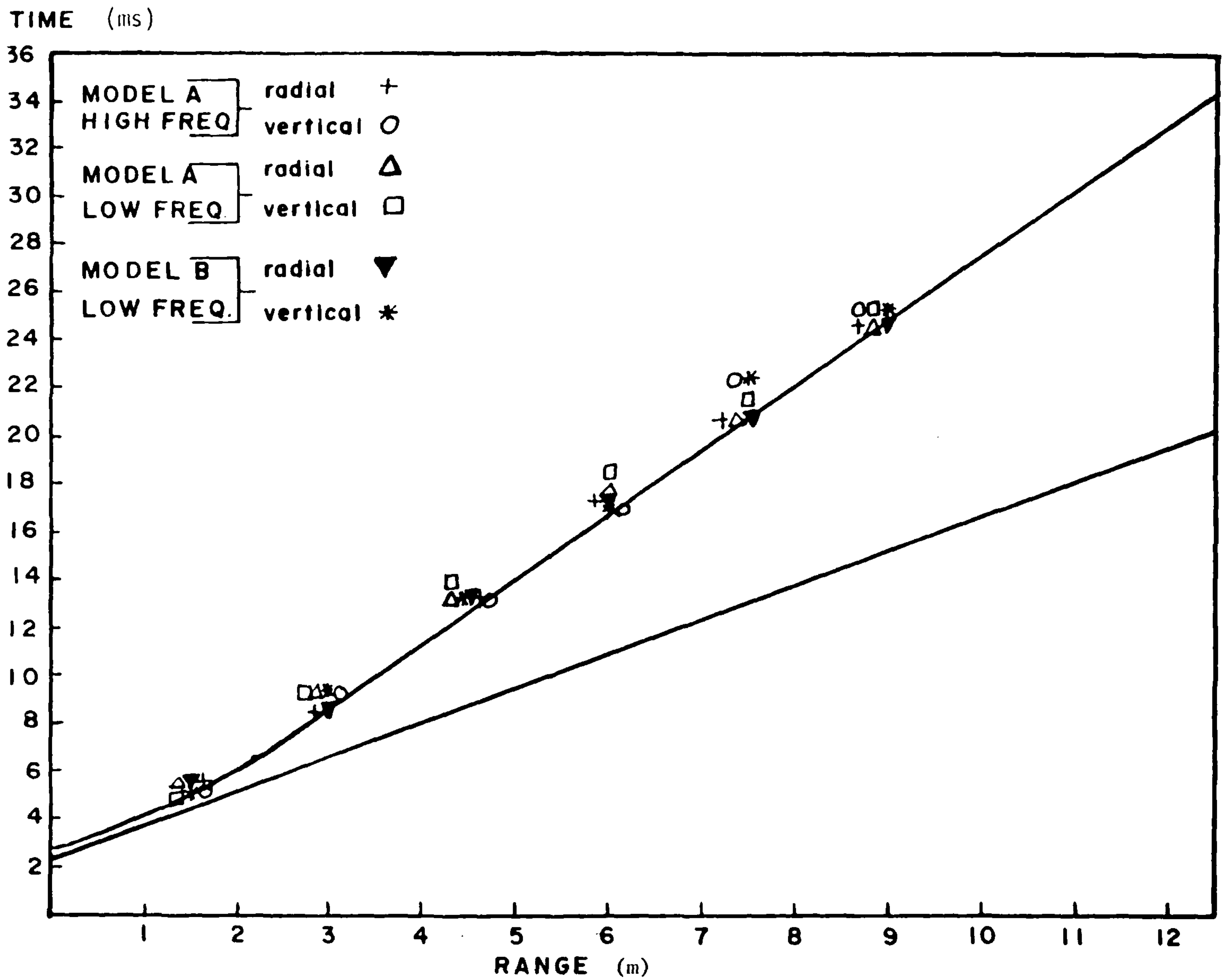


Figure 17. Comparison of true versus picked arrival times for no thin layer cases.

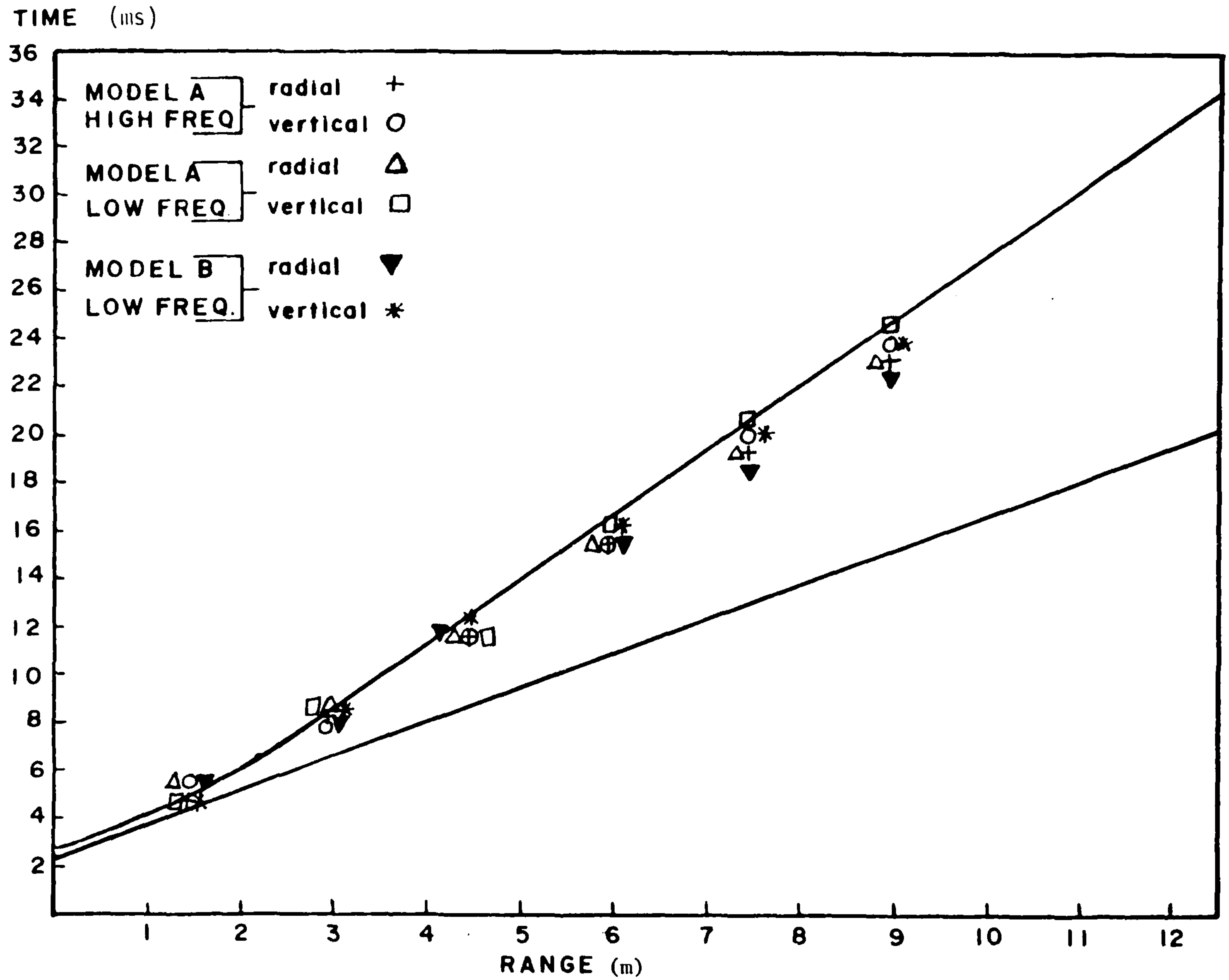


Figure 18. Comparison of true versus picked arrival times for 0.06 m thin layer case.

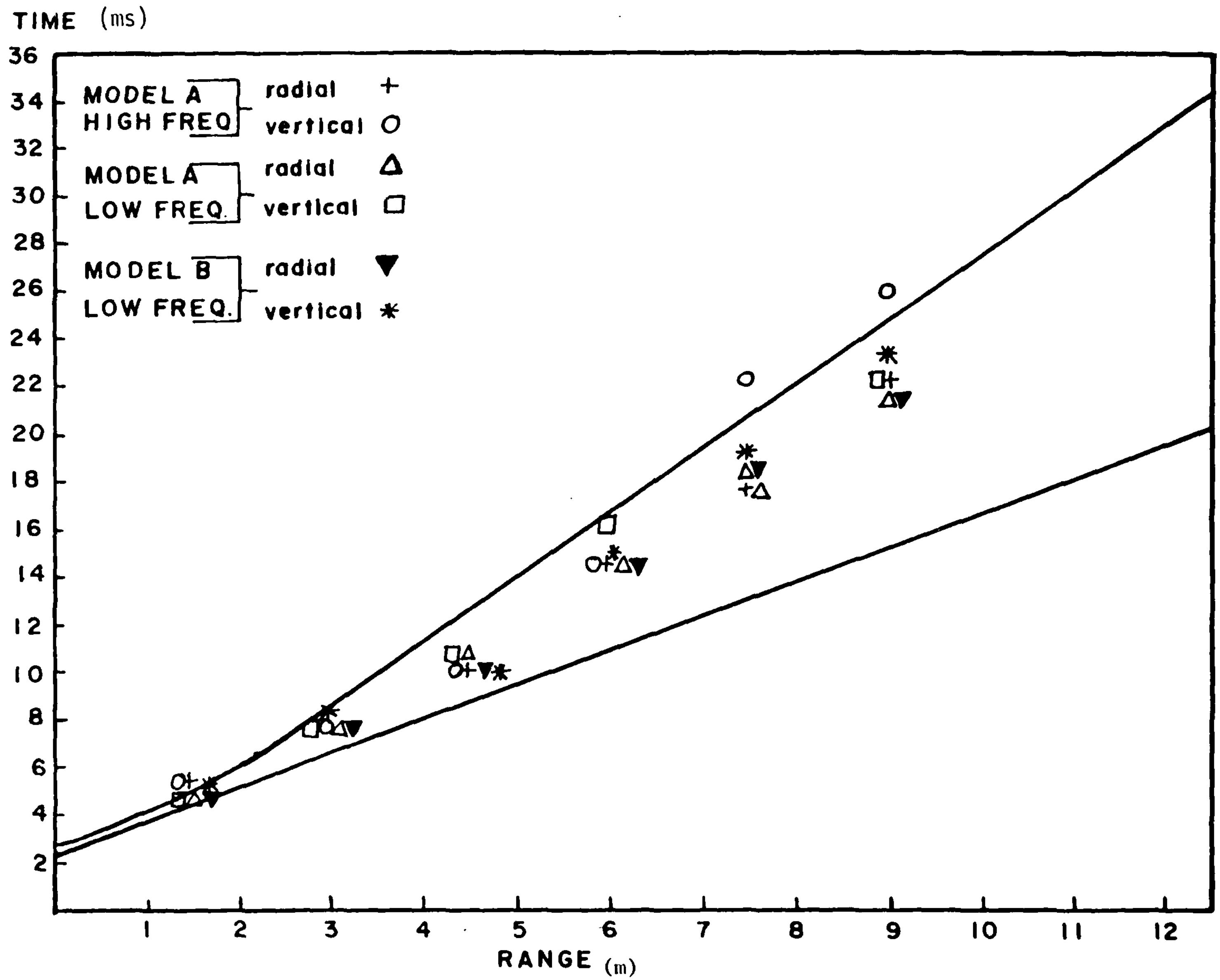


Figure 19. [illegible] true versus picked arrival times for 0.12 m thin layer cases.

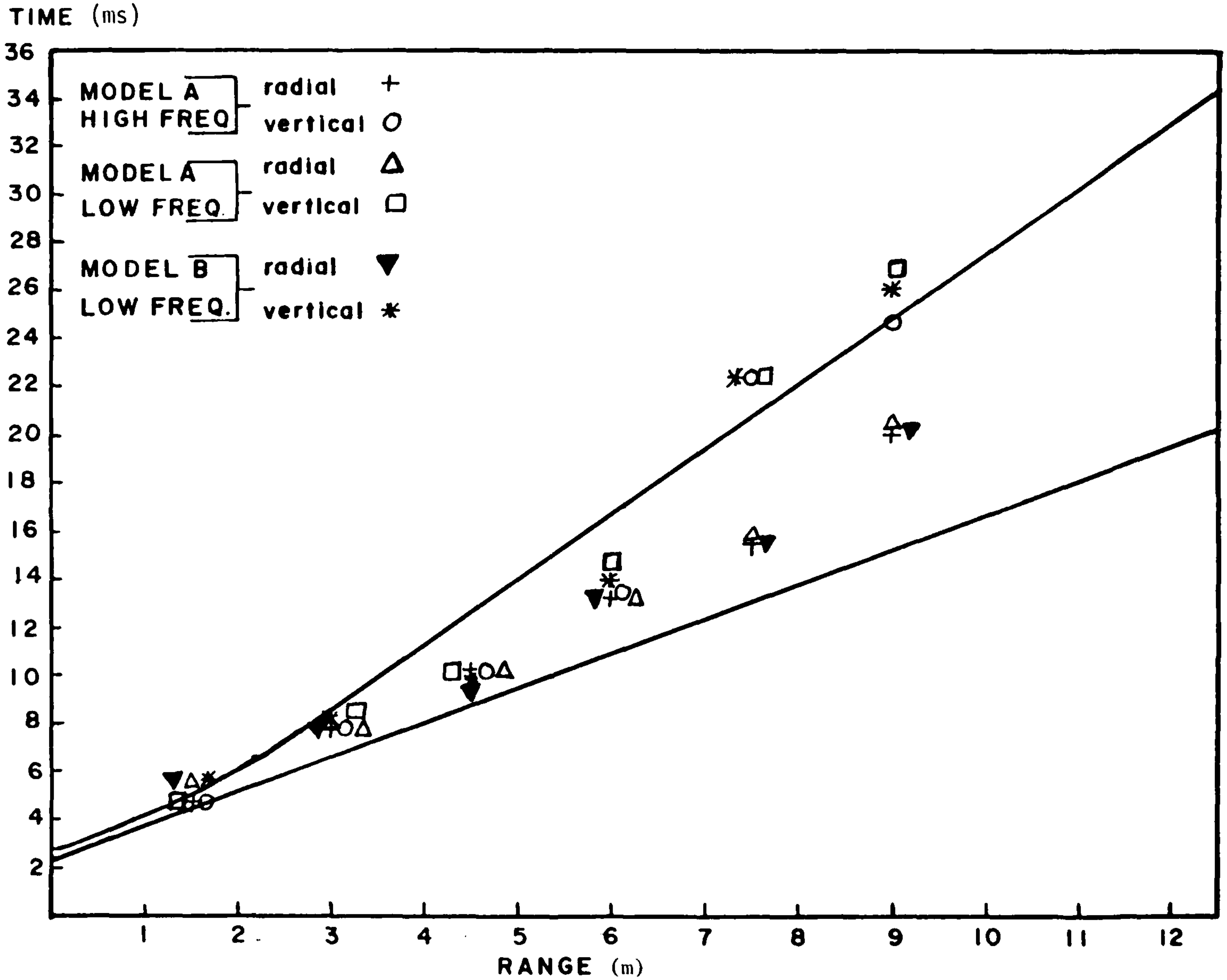


Figure 20. Comparison of true versus picked arrival times for 0.25 m thin layer cases.

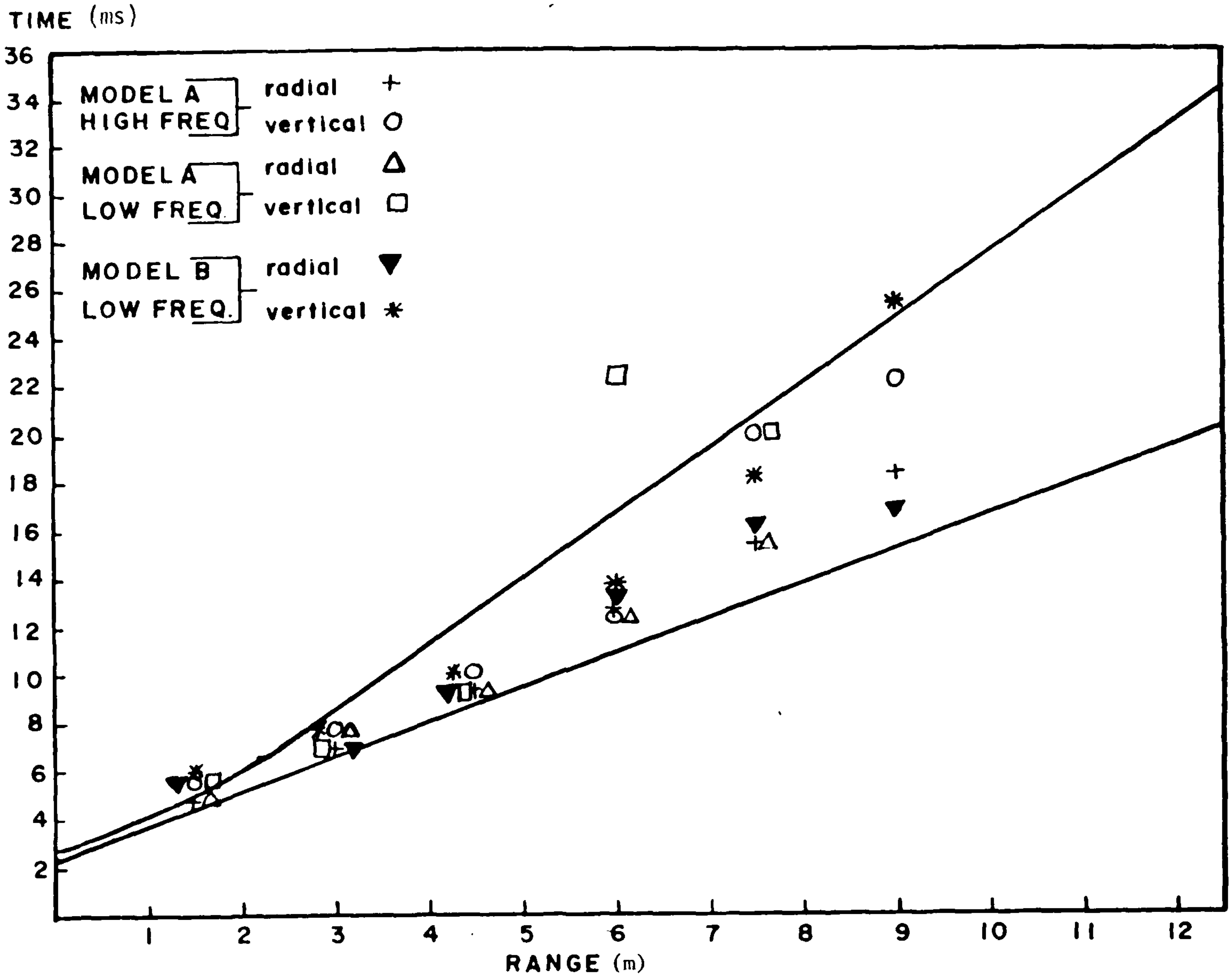


Figure 21. Comparison of true versus picked arrival times for 1 m thin layer cases.

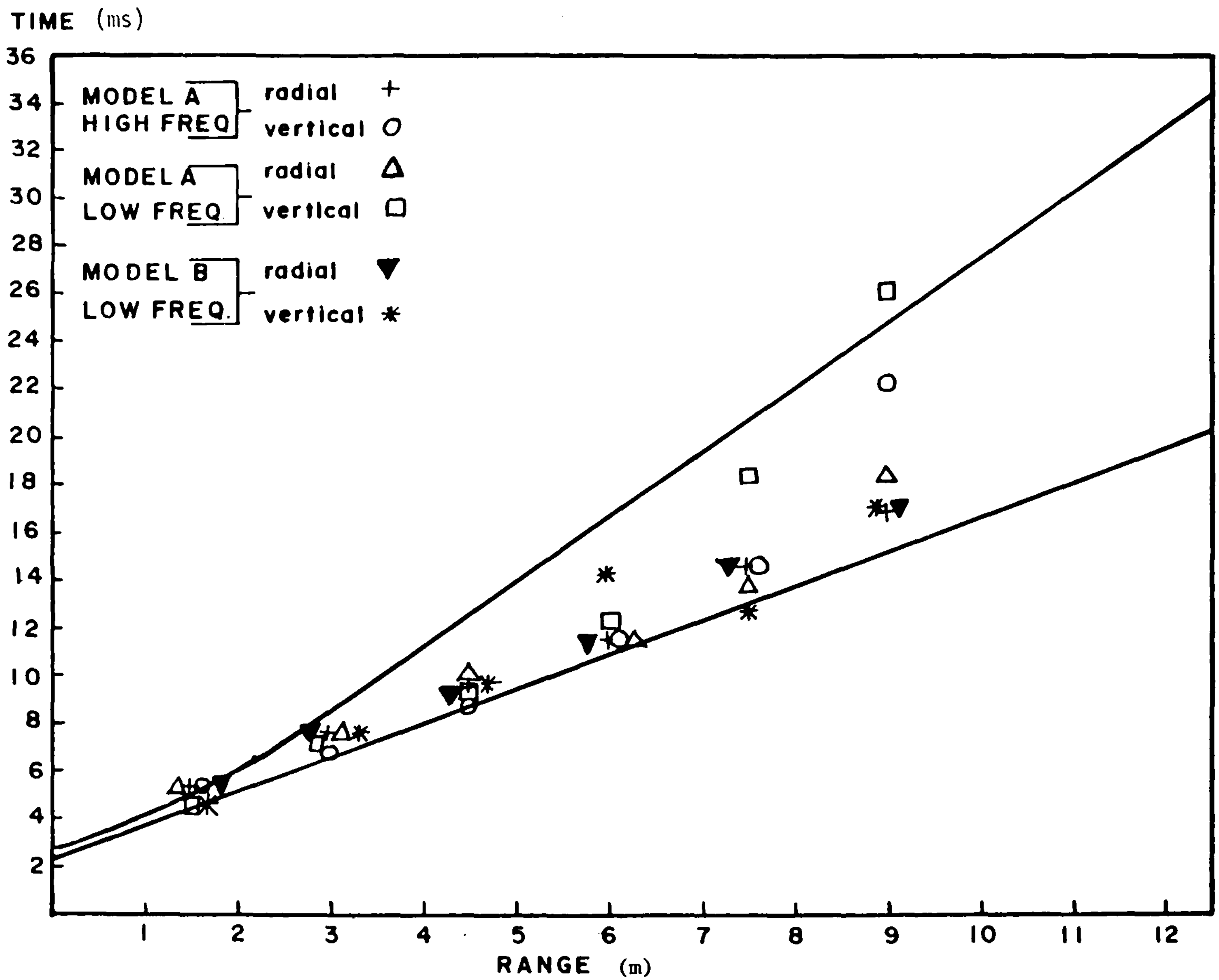


Figure 22. Comparison of true versus picked arrival times for 1 m thin layer cases.

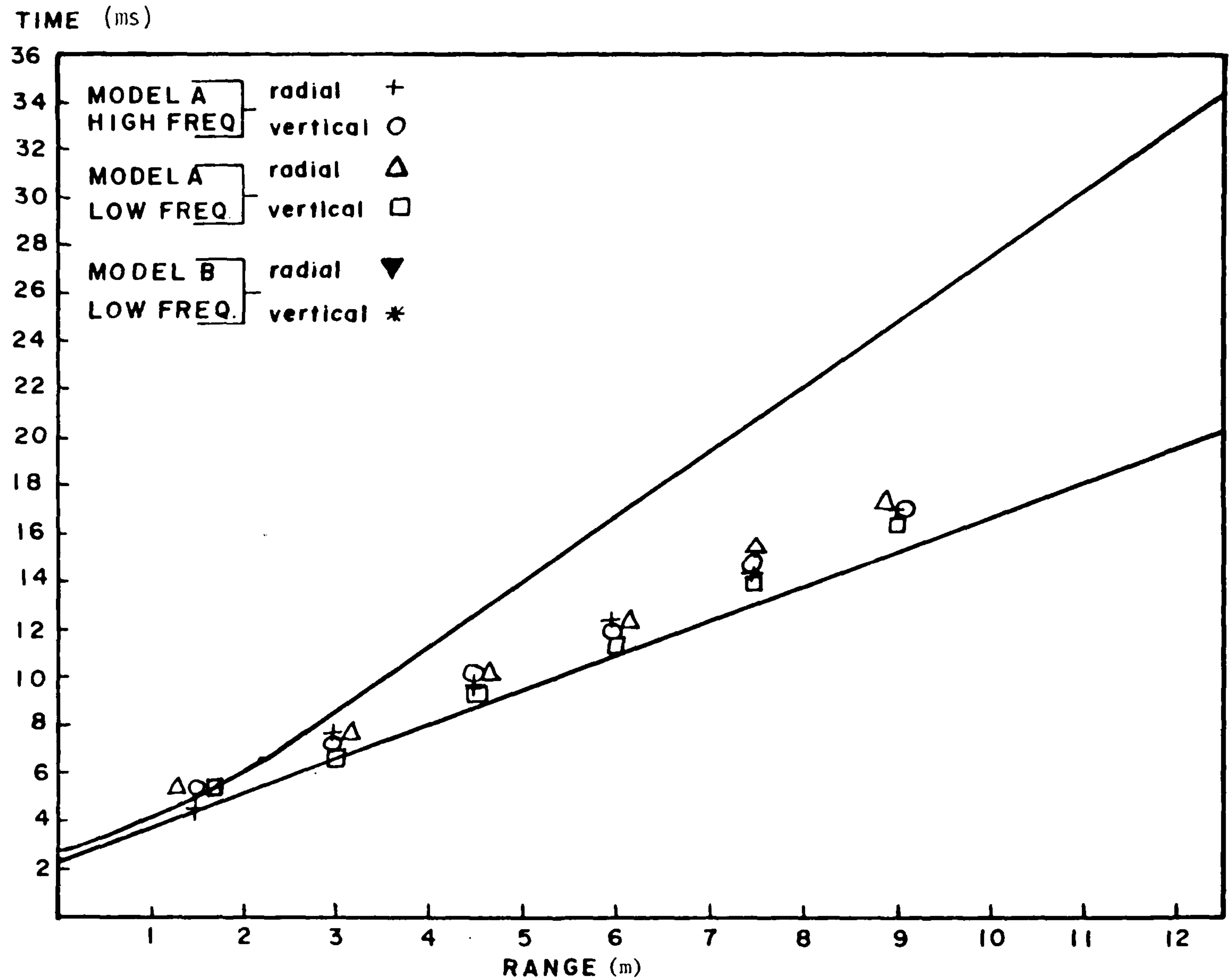


Figure 23. Comparison of true versus picked arrival times for 2.35 m thin layer cases.

To interpret the synthetic record section arrival times, they were treated as fully reversed times (times for the reverse were made identical to the forward times) from a 6-geophone refraction spread with a geophone spacing of 1.5 m. The code requires that a layer number be assigned to each arrival time. For each case, the arrival at the first geophone was said to be associated with Layer 1; all other arrivals were assigned to Layer 2.

Results from the interpretation exercise are presented in Figures 24 through 29, starting with the results for the 0.06 m layer in Figure 24 and ending with the 2.35 m layer case in Figure 29. Intuition would suggest that a layer too thin to be detected as a discrete unit would simply be averaged in some thickness weighted fashion with the velocities of the surrounding material. In some of the interpretations, this appears indeed to have happened (for example, the 0.06 m layer case in Figure 24, perhaps Figure 25 which is the 0.12 m case, and the 0.25 m layer case in Figure 26). For the thicker thin layer cases, 0.50 m in Figure 27 and 1 m in Figure 28, the interpreted subsurface models are clearly not anywhere near being a thickness weighted average of the thin layer and surrounding material. For the 0.50 m layer model, we obtain an interpreted section with a velocity interface at approximately 2.3 m depth, a significant departure from the true depth of 1 m. In the interpretation of the 1 m thick layer shown in Figure 28, the interpreted velocities are near the true values; however, the depth of the velocity interface is significantly greater than the true value, and the code has placed topography on the interface in an effort to fit the first break times. The 2.35 m interpretation shown in Figure 29 is quite close to the true subsurface model. The velocity interface is at the right depth, 1 m, while the velocities are near the true values. The 2.35 m layer case is probably not properly considered as a thin layer case since the 2.35 m caliche layer is in direct contact with the underlying half-space with almost the same velocities. The good correlation between the interpreted and true structures for the 2.35 m case verifies the interpretational capabilities for the SIPT computer code.

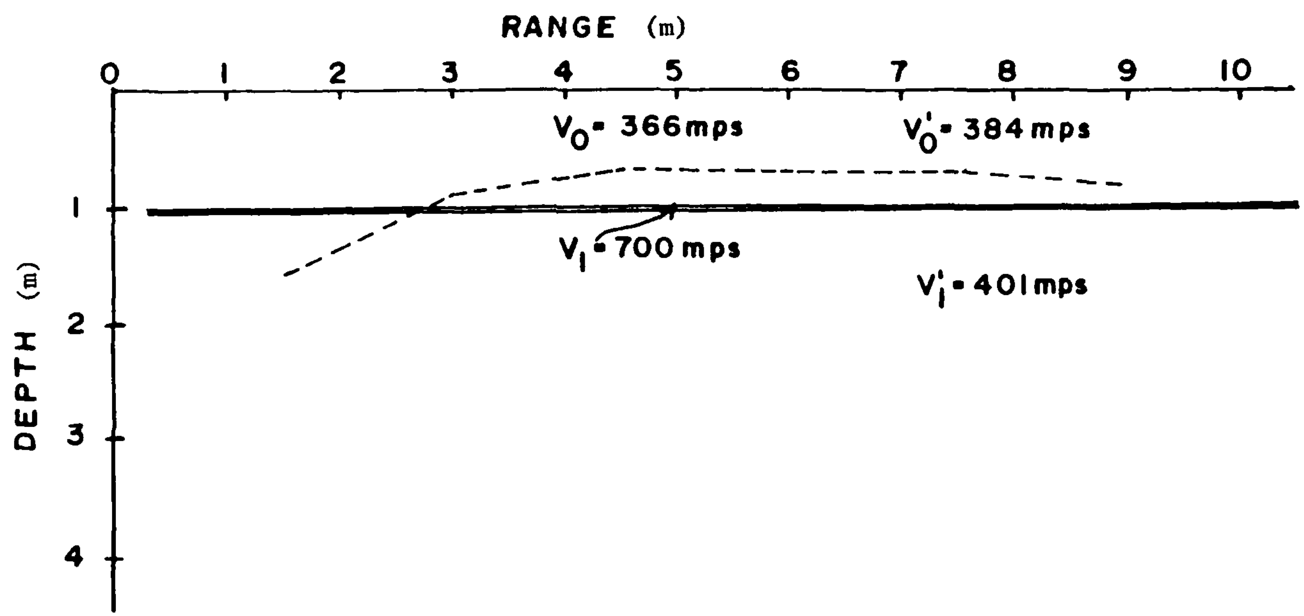


Figure 24. True versus interpreted subsurface structure for 0.06 m thin layer cases. (Solid lines and unprimed velocities indicate the structure used for computation of the synthetic seismograms. The dotted line and primed velocities are the subsurface structure obtained by first arrival interpretation of the synthetic record sections.) The travel times used were picked from the model B vertical record section.

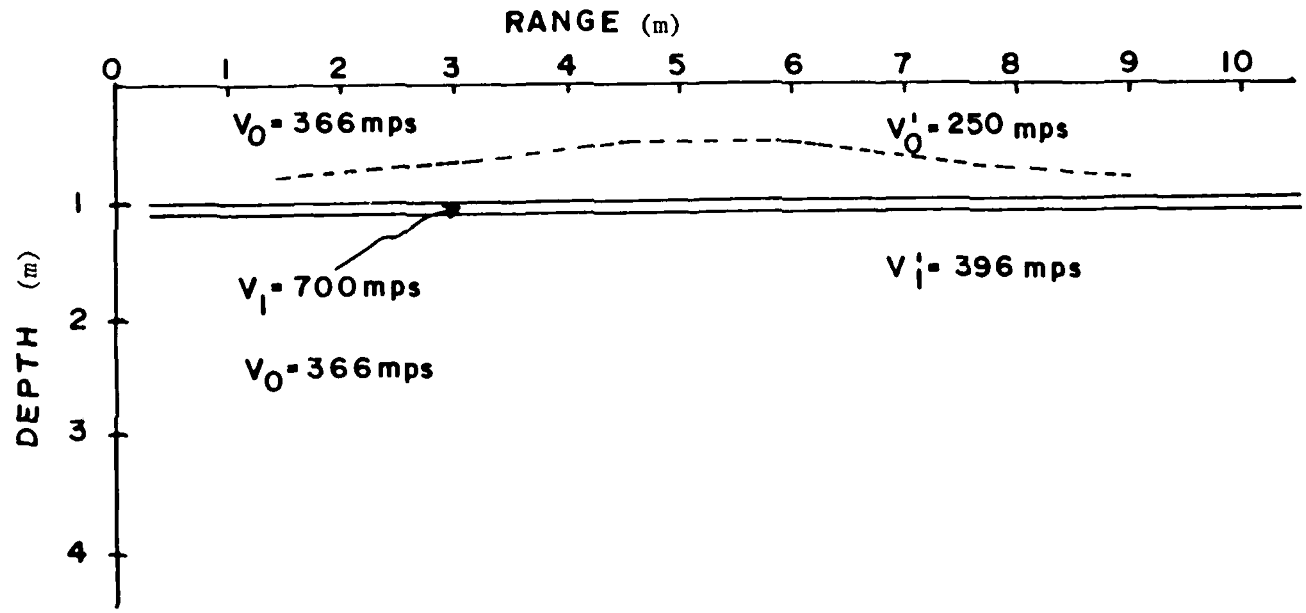


Figure 25. Comparison of true versus interpreted subsurface structure for the 0.12 m cases. The travel times used were picked from the model B vertical record section.

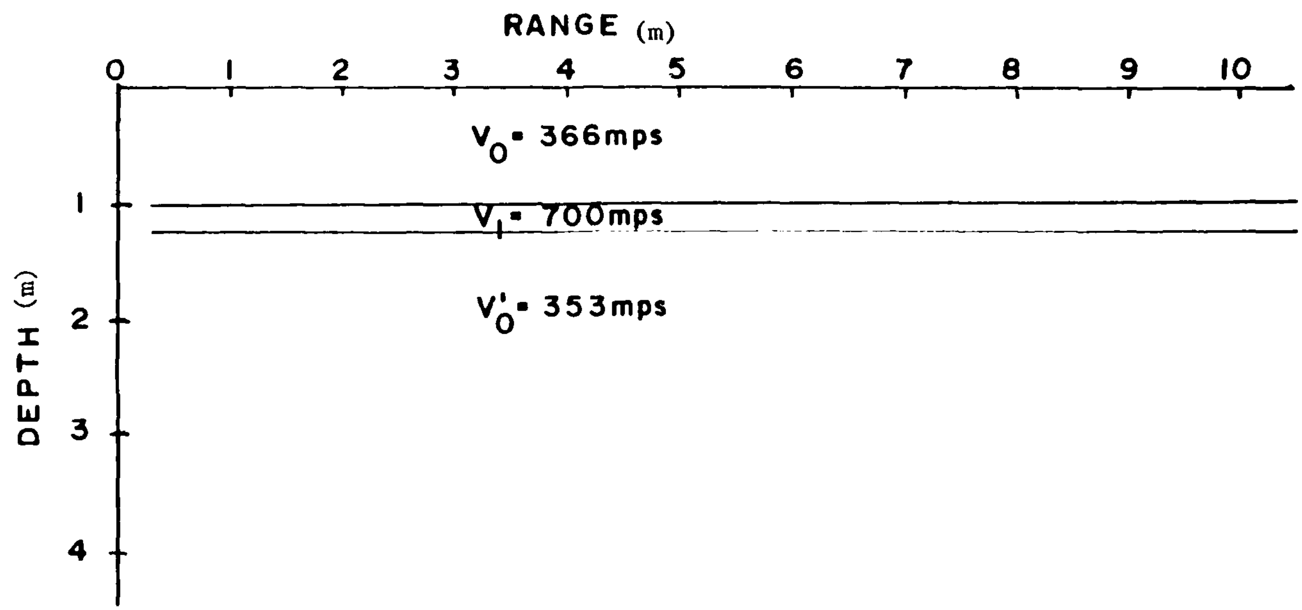


Figure 26. Comparison of true versus interpreted subsurface structure for the 0.25 m cases. The travel times used were picked from the model B vertical record section.

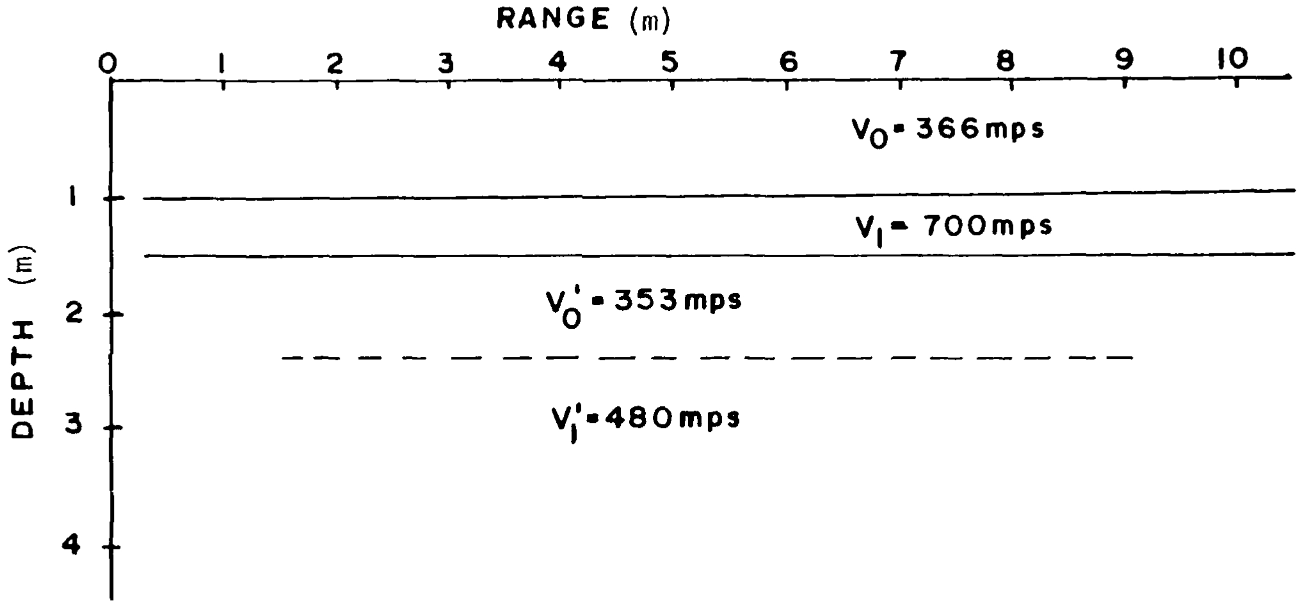


Figure 27. Comparison of true versus interpreted structure for the 0.50 m cases. The travel times used were picked from the model B vertical record section.

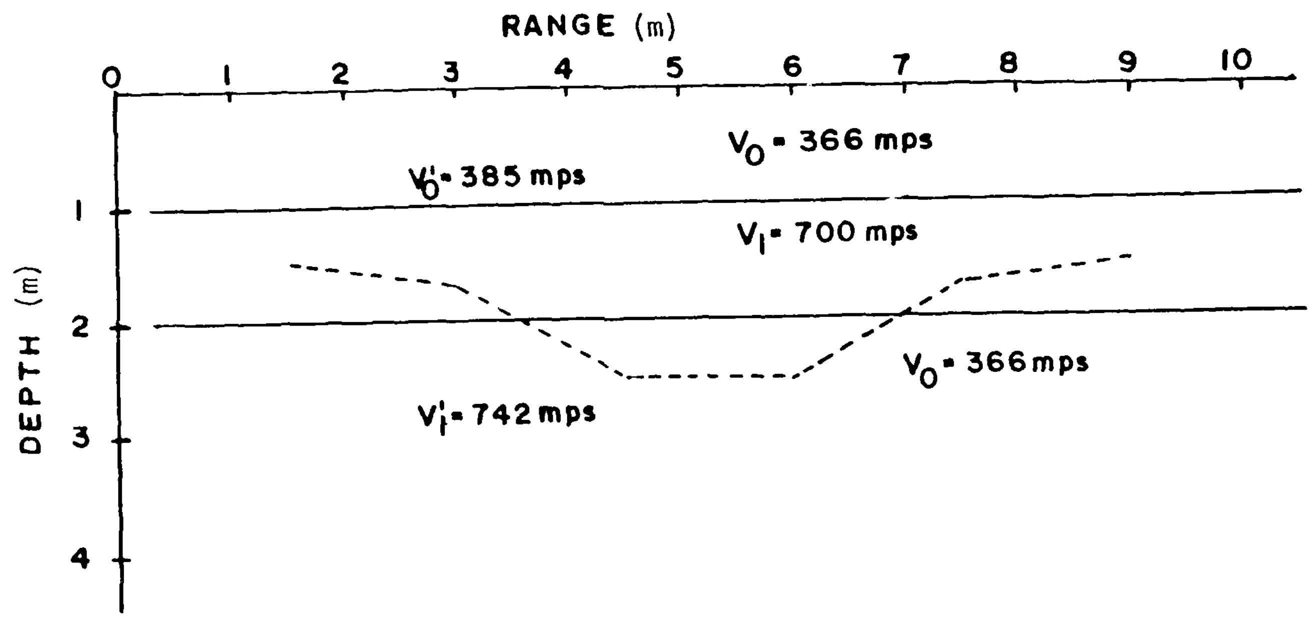


Figure 28. Comparison of true versus interpreted structure for the 1 m cases. The travel times used were picked from the model B vertical record section.

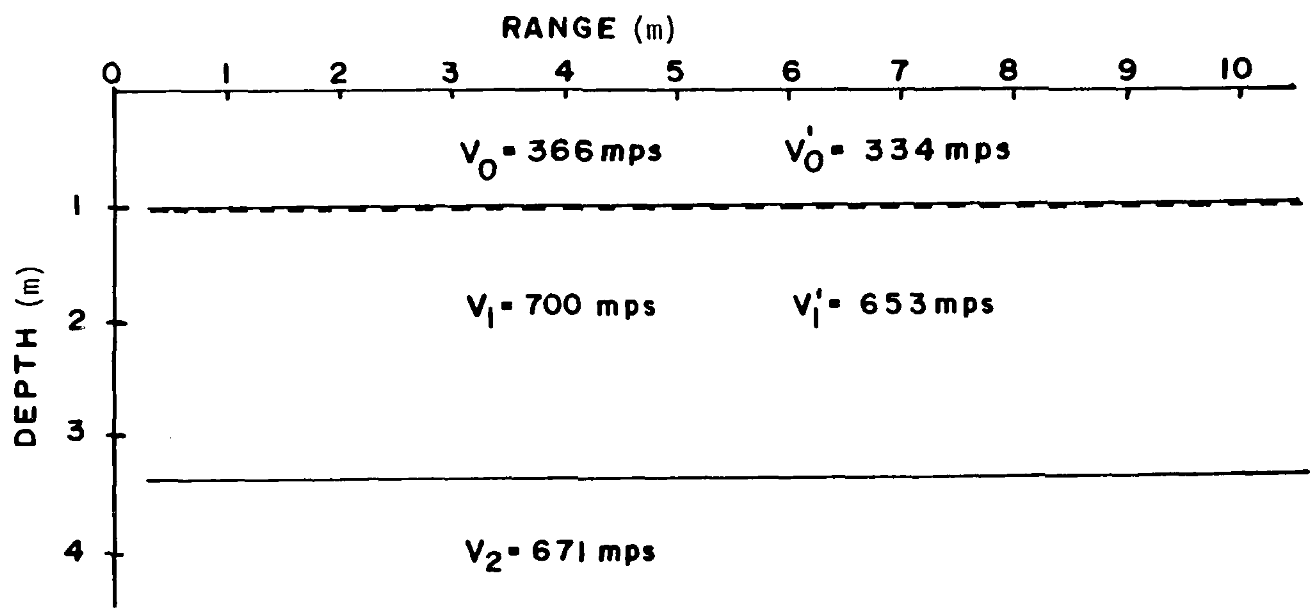


Figure 29. Comparison of true versus interpreted structure for the 2.35 m cases. The travel times used were picked from the model A vertical high frequency calculations.

DISCUSSION

Interpretations of the synthetic record sections have shown that the thin layer effects can, in certain case, have fairly deleterious effects upon the results of shallow refraction surveys. Intuition would suggest that in cases where the thin layer is not directly detectable, the thin layer properties would essentially be averaged in (on a thickness weighted basis), with the properties of the surrounding material in the interpreted model obtained from the refraction survey. Although this appears to be the case in certain instances, in other cases the presence of a thin layer may induce topography or fault-like features in the interpreted subsurface model even though the true model consists entirely of plane layered horizontally lying geologic structures.

This study has been specific rather than general in that we have focused upon a subsurface model appropriate for the alluvium-caliche situation. Additional work will be required to develop more general rules regarding wavelength-layer thickness ratios for which thin layer effects may occur. It is likely, however, that the results obtained apply to refraction surveys conducted in any area where the wavelengths are large compared to the layer thicknesses. The presence of time gaps in the record sections (similar to those shown in Figure 1) or the presence of extremely emergent first arrivals (similar to those seen in the synthetic record sections) should alert the interpreter that existence of thin layer effects is possible. In these cases, the results of the refraction surveys should be corroborated by borehole data or other independent supporting information. Some of the results suggest that use of radial geophones for refraction surveys may be advantageous in the detection of thin layer first arrivals.

The results of this study also have implications for the interpretation of ground shock data from high-explosive simulation tests. Ground shock analysts should keep in mind that unexpected effects may occur in the presence of geologic layers whose thickness is relatively small compared to the wavelengths of the ground motions propagating through the test bed. In some instances, thin layer effects might be erroneously attributed to relief effects or other phenomena.

Increasing the frequency of the source pulse might increase the detectability of the thin layer and reduce the severity of the thin layer effects. This appears not to have been the case, at least for the moderately higher frequency source used, since arrival time data for the high frequency source shown in Figures 17 through 23 are in most cases indistinguishable from the lower frequency data. Increasing the source frequency considerably alters the appearance of the waveforms as shown in the comparison presented in Figure 30 for the vertical case and Figure 31 for the radial case.

Reference 18 presents a discussion of the pervasiveness of the hidden layer or blind zone problem for shallow refraction surveys when standard first arrival interpretation techniques are used. As discussed in Reference 18, hidden layer problems can cause serious errors in the interpretation of shallow refraction surveys for engineering site characterization. Hidden layer problems, coupled with the thin layer effects presented in this report, suggest the need for a more robust interpretation method for shallow seismic refraction surveys. Users of the seismic refraction technique should be aware of its limitations and, whenever possible, should rely upon multiple sources of geophysical data for construction of subsurface geologic models.

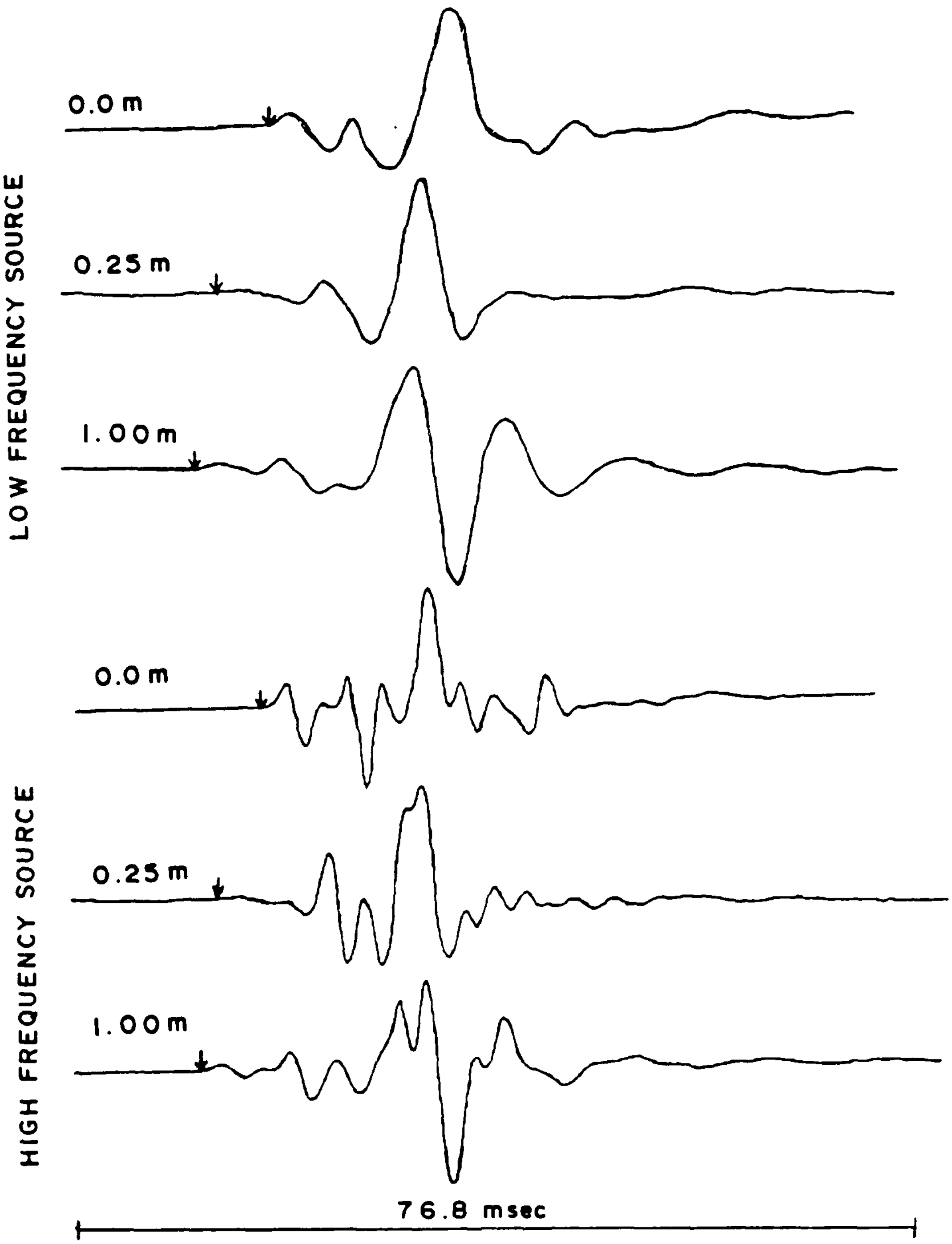


Figure 30. Comparison of vertical high and low frequency waveforms for the 6 m range, model A.

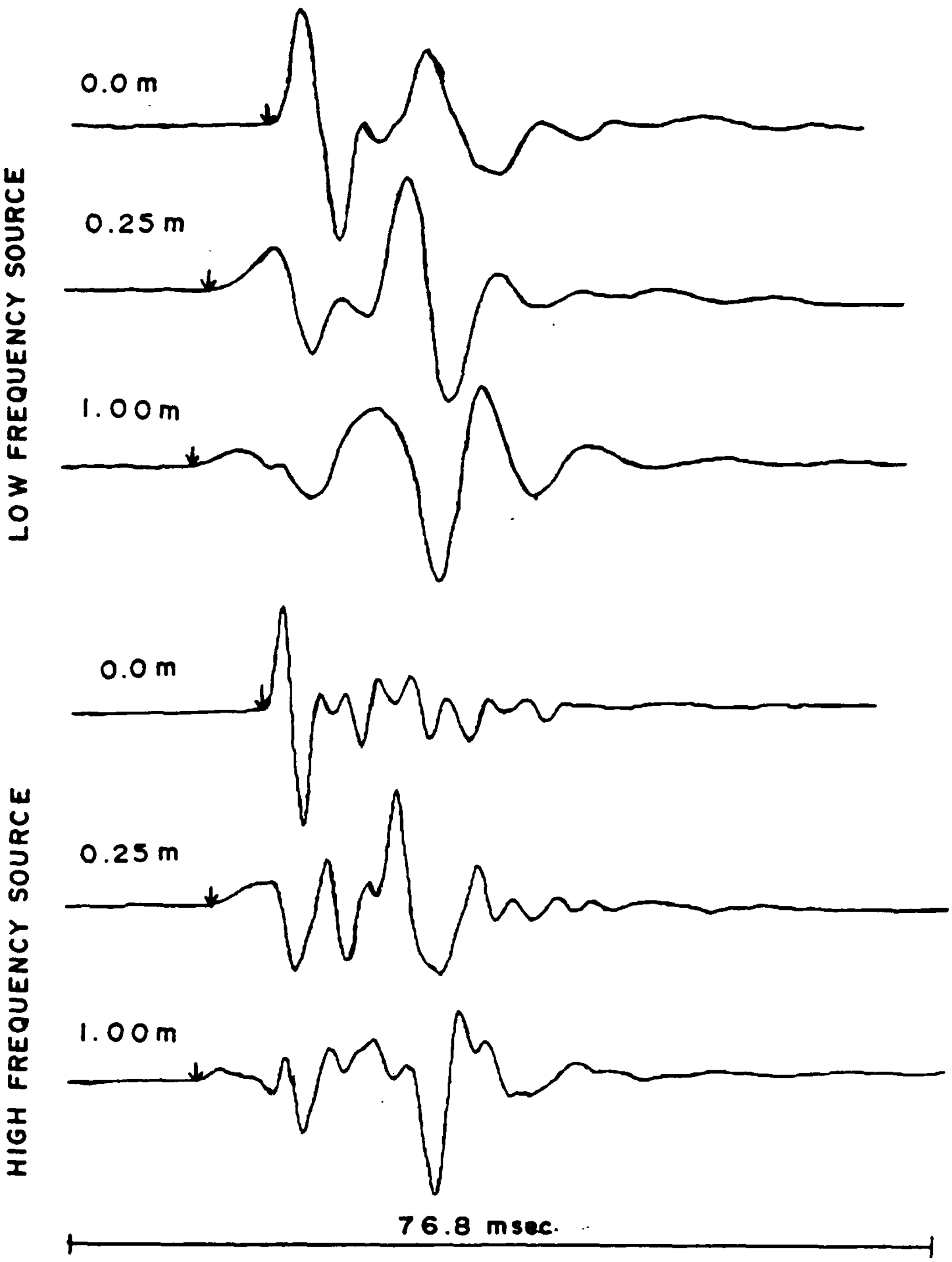


Figure 31. Comparison of radial high and low frequency waveforms for the 6 m range, model A.

REFERENCES

1. Widess, M.B., "How Thin is a Thin Bed?" Geophysics, Vol 38, pp 1176-1180, 1973.

2. Robertson, James D. and Nogami, H.H., "Complex Seismic Trace Analysis of Thin Beds," Geophysics, Vol 49, No 4, pp 344-352, 1984.

3. Koefoed, O. and de Voogd, N., "The Linear Properties of Thin Layers with an Application to Synthetic Seismograms over Coal Seams," Geophysics, Vol 45, pp 1254-1268, 1980.

4. Press, F., Oliver, J., and Ewing, M., "A Seismic Model Study of Refractions from a Layer of Finite Thickness," Geophysics, Vol 19, No 3, pp 388-401, 1954.

5. Levin, F.K., and Ingram, J.D., "Head Waves from a Bed of Finite Thickness," Geophysics, Vol 27, No 6, pp 753, 1962.

6. Spencer, T.W., "Refraction along a Layer," Geophysics, Vol 30, No 3, pp 369-388, 1965.

7. Rosenbaum, J.H., "Refraction Arrivals through Thin High-Velocity Layers," Geophysics, Vol 30, No 2, pp 204-212, 1965.

8. Mellman, G.R. and Helmberger, D.V., "High Frequency Attenuation by a Thin High Velocity Layer," Bulletin of the Seismological Society of America, Vol 64, No 5, pp 1383-1388, 1974.

9. Sherwood, J.W.C., "Refraction along an Embedded High Speed Layer," Seismic Refraction Prospecting, The Society of Exploration Geophysicists, Tulsa, Oklahoma, pp 138-151, 1967.

10. O'Brien, P.N.S., "The Use of Amplitudes in Seismic Refraction Survey," Seismic Refraction Prospecting, The Society of Exploration Geophysicists, Tulsa, Oklahoma, pp 85-118, 1967.

11. Domzalski, W., "Some Problems of Shallow Refraction Investigations," Geophysical Prospecting, Vol 4, pp 140-166, 1956.

12. Kind R., "The Reflectivity Method for a Buried Source," Journal of Geophysics, Vol 44, pp 603-612, 1978.

13. Fuchs, K. and Muller, G., "Computation of Synthetic Seismograms with the Reflectivity Method and Comparison with Observations," Geophys. J.R. Astro. Soc., Vol 23, pp 417-433, 1971.

14. Olsen, K.H. and Braille, L.W., "Seismograms of Explosions at Regional Distances in the Western U.S.: Observations and Reflectivity Method Modeling," Identification of Seismic Sources - Earthquake or Underground Explosion, edited by E. Husebye and S. Mykkehveit, D. Reidel Publishing Co., Dordrecht, Holland, 1981.

REFERENCES (Concluded)

15. Fuchs, K., "The Reflection of Spherical Waves from Transition Zones with Arbitrary Depth-Dependent Elastic Moduli and Density," J. Phys. Earth, Vol 16, Special Issue 27, 1968.

16. Scott, J.H., Tibbets, B.L., and Burdick, R.G., "Computer Analysis of Seismic Refraction Data," USBM R.I. 7515, p 95, 1972.

17. Scott, J.H., "Seismic Refraction Modeling by Computer," Geophysics, Vol 38, No 2, pp 271-284, 1973.

18. Won, I.J. and Bevis, Michael, "The Hidden Layer Problem Revisited," Geophysics, Vol 49, No 11, 1984.

END
DTIC
8-86